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## WITH CONTENTS

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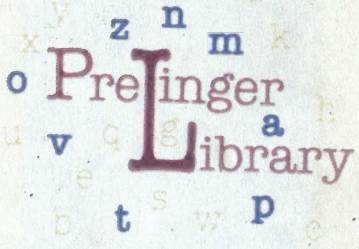


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# MARKETING CANTALOUPS AND OTHER MUSKMELONS[1]

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## VARIETIES AND TYPES

Distinct varieties of cantaloups are many in number. Regardless of varieties cantaloups are generally referred to commercially as "salmon meat" or "salmon tint", "pink meat", and "green meat", in accordance with the color of the edible portion. Both the salmon meats and the pink meats are grown for market in most of the leading districts from California to the Atlantic, and a large part of the commercial crop is included under these classifications. Green meats were formerly commercially important in the Eastern and Southeastern States, but have been largely replaced by salmon- or pink-meat varieties.

In some instances variety names are used in price quotations. In the Federal market news reports varieties [2] classed as salmon meats include Hale Best, Pollock 10–25, and Abbott Pearl (Pearl Pink); varieties classed as pink meats include Burrell Gem, Hearts of Gold, Edwards Perfecto, Osage, and Tiptop. There is no sharp distinction in color of the edible portion of the salmon-meat and pink-meat types, and for this reason there is some variation in the commercial classification of varieties in different districts and under different conditions.

[1] The term "other muskmelons" as used in this publication refers chiefly to casaba, Honey Ball, Honey Dew, and Persian melons. The term "melons" also refers to this group.

Acknowledgment is made of the assistance rendered by field representatives of this Bureau and various States who supplied specific information relating to certain producing districts.

[2] A more detailed description of varieties is contained in the following publication: BEATTIE, W. R., MUSKMELONS. U.S. Dept. Agr. Farmers' Bull. 1468, 38 pp., illus. 1926.

Changes in popularity and production of varieties have been marked in recent years. Efforts have been made to develop new varieties which are highly resistant to disease and which can be allowed to ripen on the vine and still be satisfactory for shipping. Varieties recently developed in western districts include the Melodew, Weaver Special, McDaniel Nugget, and Jagger Mildew Resistant.

Honey Dew, Honey Ball, casaba, Persian melons, and a few other varieties are produced commercially in some of the Western States. This group of miscellaneous melons, particularly Honey Dew and Honey Ball, has increased greatly in commercial importance in the last decade.

## PRODUCING DISTRICTS AND PRODUCTION

Cantaloups are grown commercially in many districts throughout the United States. The commercial acreage of cantaloups and other

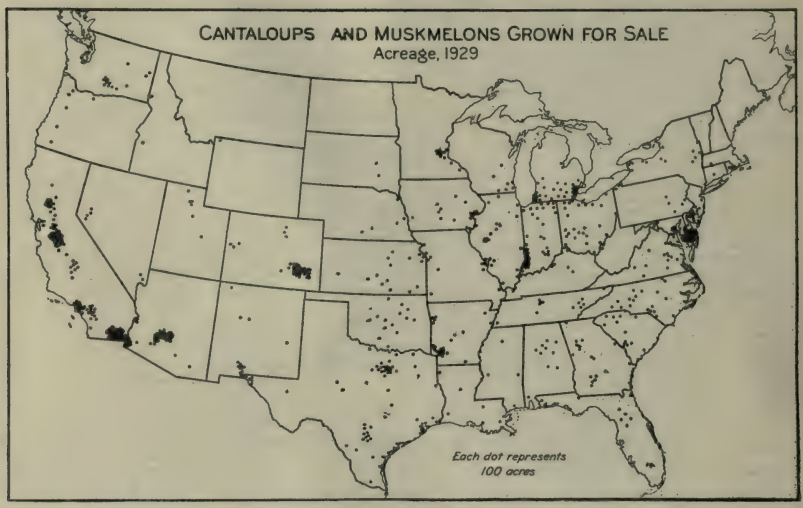


FIGURE 1.—The census listed 129,000 acres of cantaloups and muskmelons grown for sale in the United States in 1929. These melons are grown in many of the States, but nearly two thirds of the commercial acreage was in California, Arizona, and Colorado, according to estimates for the period 1928–32.

muskmelons (including chiefly Honey Dew, Honey Ball, casaba, and Persian melons) in 25 States for which official estimates are available varied in the period 1928 to 1932 from 102,000 acres in 1928 to 138,000 acres in 1931 (table 1). The census figures for all States showed 129,000 acres grown for sale in 1929. Commercial production has become largely concentrated in districts that have proven to be well adapted to this crop. These include districts in Imperial Valley, Calif., north-central California, south-central Arizona, southeastern Colorado, southern New Mexico, southwestern Arkansas, southwestern Indiana, southwestern and southeastern Michigan, New Jersey, Delaware, Eastern Shore of Maryland, the Carolinas, Texas, Washington, and a number of other States (fig. 1).

During the 5 years ended in 1932, approximately 75 percent of the commercial crop of cantaloups and other muskmelons was grown in three Western States—California, Arizona, and Colorado. More than half of the production was in California. The crop produced in Colorado, New Mexico, and States farther west is referred to in this bulletin as the western crop.

TABLE 1.—*Acreage and production for market of cantaloups and other muskmelons* [1]

| Group and State or district | Acreage | | | | | Production [2] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1928 | 1929 | 1930 | 1931 | 1932 | 1928 | 1929 | 1930 | 1931 | 1932 |
| Early shipping group: | *Acres* | *Acres* | *Acres* | *Acres* | *Acres* | *1,000 crates* | *1,000 crates* | *1,000 crates* | *1,000 crates* | *1,000 crates* |
| California, Imperial Valley | 33,460 | 38,360 | 50,900 | 51,640 | 45,750 | 6,224 | 6,713 | 5,752 | 7,849 | [3] 6,405 |
| Florida | 920 | 600 | 600 | 250 | 200 | 37 | 36 | 30 | 12 | 15 |
| Texas, early district | 140 | 740 | 1,260 | 540 | 150 | 16 | 70 | 113 | 59 | 15 |
| Total | 34,520 | 39,700 | 52,760 | 52,430 | 46,100 | 6,277 | 6,819 | 5,895 | 7,920 | [3] 6,435 |
| Second-early shipping group: | | | | | | | | | | |
| Arizona | 10,000 | 11,500 | 15,700 | 13,800 | 12,500 | 1,800 | 2,024 | 2,088 | 1,725 | [3] 1,500 |
| Arkansas | 6,000 | 2,400 | 2,550 | 2,600 | 3,350 | 564 | 185 | 115 | 182 | 234 |
| California, other than Imperial Valley | 12,050 | 14,020 | 15,330 | 15,680 | 18,180 | 2,470 | 2,734 | 2,851 | 2,540 | [3] 3,036 |
| Georgia | 650 | 600 | 750 | 800 | 1,100 | 52 | 48 | 75 | 56 | 77 |
| Nevada, Moapa district | 250 | 170 | 150 | 120 | 190 | 50 | 23 | 14 | 20 | 12 |
| North Carolina | 2,310 | 1,000 | 620 | 1,100 | 2,600 | 261 | 70 | 53 | 99 | 182 |
| Oklahoma | 500 | 500 | 500 | 530 | 560 | 34 | 38 | 38 | 45 | 45 |
| South Carolina | 640 | 510 | 600 | 1,200 | 2,000 | 56 | 26 | 72 | 150 | 190 |
| Texas, other than early district | 1,570 | 1,500 | 2,320 | 11,530 | 7,300 | 141 | 111 | 139 | [3] 865 | [3] 387 |
| Total | 33,970 | 32,200 | 38,520 | 47,360 | 47,780 | 5,428 | 5,259 | 5,445 | [3] 5,682 | [3] 5,663 |
| Intermediate shipping group: | | | | | | | | | | |
| Delaware | 2,200 | 2,200 | 2,200 | 2,500 | 2,700 | 297 | 231 | 187 | 225 | 338 |
| Illinois | 900 | 900 | 900 | 1,020 | 1,070 | 97 | 94 | 63 | 82 | 96 |
| Indiana | 4,640 | 4,180 | 4,390 | 4,610 | 4,610 | 524 | 418 | 255 | 438 | 507 |
| Maryland | 6,040 | 6,800 | 7,010 | 7,550 | 8,100 | 676 | 578 | 386 | 680 | 834 |
| New Mexico | 1,400 | 1,570 | 1,800 | 2,100 | 3,400 | 189 | 196 | 243 | 258 | [3] 391 |
| Tennessee | 470 | 120 | 170 | 220 | 240 | 33 | 10 | 13 | 15 | 18 |
| Washington | 1,750 | 1,850 | 1,950 | 1,600 | 1,650 | 192 | 278 | 224 | 197 | 198 |
| Total | 17,400 | 17,620 | 18,420 | 19,600 | 21,770 | 2,008 | 1,805 | 1,371 | 1,895 | [3] 2,382 |
| Late shipping group: | | | | | | | | | | |
| Colorado | 9,000 | 11,000 | 10,000 | 8,100 | 7,370 | 1,170 | 2,530 | 2,000 | 1,134 | 1,106 |
| Iowa | 780 | 580 | 520 | 620 | 900 | 78 | 39 | 42 | 53 | 90 |
| Kansas | 450 | 450 | 450 | 450 | 450 | 57 | 54 | 40 | 50 | 54 |
| Michigan | 3,000 | 3,400 | 3,800 | 4,000 | 4,200 | 300 | 357 | 437 | 420 | 420 |
| Nevada, other than Moapa district | 220 | 320 | 280 | 260 | 260 | 36 | 40 | 44 | 22 | 24 |
| New Jersey | 3,000 | 2,500 | 3,100 | 4,000 | 5,000 | 480 | 275 | 388 | 420 | 625 |
| Ohio | ------- | 300 | 360 | 540 | 650 | ------- | 27 | 41 | 57 | 72 |
| Oregon | ------- | 600 | 800 | 700 | 600 | ------- | 60 | 120 | 122 | 96 |
| Utah | ------- | ------- | ------- | 250 | 700 | ------- | ------- | ------- | 42 | 54 |
| Total | 16,450 | 19,150 | 19,310 | 18,920 | 20,130 | 2,121 | 3,382 | 3,112 | 2,320 | 2,541 |
| Total | 102,340 | 108,670 | 129,010 | 138,310 | 135,780 | 15,834 | 17,265 | 15,823 | [3] 17,817 | [3] 17,021 |

[1] Other melons include chiefly casaba, Honey Ball, Honey Dew, and Persian melons, but not watermelons.

[2] In terms of standard crates containing approximately 60 pounds.

[3] Includes some quantities not harvested on account of market conditions as follows: Arizona, 438,000 crates in 1932; California, Imperial Valley, 1,693,000 crates, and California, other than Imperial Valley, 758,000 crates in 1932; Texas, other than early district, 433,000 crates in 1931, and 182,000 crates in 1932; New Mexico, 109,000 crates in 1932.

Division of Crop and Livestock Estimates.

Production for market of cantaloups and other muskmelons in the period 1928 to 1932, stated in terms of standard crates, has ranged from 15,800,000 in 1928 to 18,000,000 in 1931. The annual per-capita commercial production for the United States in this period has ranged approximately from 8 to 9 pounds.

## SHIPMENTS

The important western producing districts are at great distances from the leading markets and the greater part of the movement from them is in car lots. The proportion of total shipments of the western crop moved by motor truck is small, although there is a considerable truck movement to points within a radius of several hundred miles of the producing districts. The estimated motor-truck shipments were less than 5 percent of the total movement in the Imperial Valley, Calif., in each of the years 1931 and 1932.

From the eastern and midwestern districts, which are much nearer to markets than are the western, a large part of the crop moves by truck. Records of these shipments for some districts are not available, but for Delaware and the Eastern Shore of Maryland in 1932 about 84 percent of the cantaloup shipments were by truck. The car-lot shipments of cantaloups reported for Michigan in 1932 totaled only 13, whereas the motor-truck shipments from the Benton Harbor market alone were equivalent to about 550 cars.

In 1932, motor-truck receipts of cantaloups in New York City were 30 percent of the total supply coming by rail and truck. For Philadelphia, the corresponding figure was 64 percent, and for Los Angeles, 94 percent. In Los Angeles, 90 percent of the miscellaneous melons came by truck, whereas in New York and Philadelphia there were practically no truck receipts of such melons, as they are grown chiefly in the Western States.

The rail-shipment figures represent the commercial movement of cantaloups and other muskmelons fairly well in the Western States, where about three fourths of the United States crop is produced. In other parts of the country, particularly in States near large eastern and midwestern markets, the rail shipments are not a good index of the commercial movement, because of the large quantities hauled to market by truck.

In 1928, carload shipments were equivalent to about 80 percent of the production for market. The proportion moved in car lots declined yearly from 1928 to 1932, when it was only slightly more than half of the production. Part of this decline was due to increased movement by truck, but in some years, particularly 1932, large quantities were not shipped because of low prices.

Carload shipments of cantaloups during the 10-year period 1923–32 varied between approximately 17,000 cars in 1932 and approximately 30,000 cars in 1925 and in 1927 (table 2).

TABLE 2.—*Car-lot shipments of cantaloups by States or districts, 1923–32*

| State or district of origin | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| Alabama | 0 | 3 | 1 | 3 | 0 | 0 | 1 | 0 | 0 | 0 |
| Arizona | 1,208 | 1,864 | 3,057 | 3,146 | 4,640 | 5,224 | 5,163 | 5,436 | 4,461 | 3,020 |
| Arkansas | 337 | 1,052 | 1,245 | 1,127 | 784 | 846 | 413 | 245 | 443 | 541 |
| California [1] | [2] 2,457 | | | | | | | | | |
| Northern district | | 0 | 70 | 98 | 0 | 81 | 428 | 100 | 0 | 5 |
| Southern district | | 1 | 0 | 2 | 1 | 2 | 16 | 42 | 7 | 9 |
| Central district | | 2,535 | 3,016 | 2,233 | 2,234 | 2,922 | 1,902 | 1,744 | 1,701 | 1,461 |
| Imperial Valley | 12,992 | 15,756 | 13,410 | 11,678 | 15,439 | 14,072 | 14,391 | 11,151 | 12,986 | 7,592 |
| Colorado | 2,195 | 2,654 | 3,224 | 3,574 | 2,995 | 2,110 | 3,195 | 2,754 | 1,733 | 1,765 |
| Delaware | 818 | 511 | 657 | 551 | 427 | 427 | 285 | 193 | 233 | 190 |
| Florida | 36 | 7 | 4 | 5 | 12 | 14 | 7 | 1 | 0 | 13 |
| Georgia | 216 | 586 | 117 | 136 | 108 | 104 | 76 | 138 | 80 | 81 |
| Idaho | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 2 | 3 | 6 |
| Illinois | 86 | 45 | 126 | 57 | 9 | 19 | 10 | 13 | 25 | 45 |
| Indiana | 681 | 822 | 1,087 | 595 | 365 | 459 | 387 | 172 | 278 | 239 |
| Iowa | 105 | 79 | 88 | 99 | 48 | 101 | 35 | 31 | 38 | 26 |
| Kansas | 28 | 17 | 18 | 2 | 1 | 9 | 7 | 3 | 12 | 4 |
| Kentucky | 0 | 0 | 10 | 5 | 0 | 0 | 0 | 0 | 0 | 0 |
| Louisiana | 1 | 7 | 12 | 43 | 4 | 4 | 4 | 3 | 0 | 26 |
| Maryland | 1,270 | 699 | 1,116 | 1,283 | 1,159 | 1,002 | 561 | 274 | 347 | 264 |
| Michigan | 306 | 114 | 146 | 84 | 74 | 52 | 16 | 13 | 16 | 13 |
| Missouri | 11 | 11 | 31 | 34 | 0 | 2 | 3 | 7 | 2 | 14 |
| Montana | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 |
| Nebraska | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Nevada | 107 | 231 | 346 | 162 | 133 | 159 | 170 | 124 | 58 | 64 |
| New Jersey | 83 | 70 | 147 | 15 | 12 | 13 | 1 | 0 | 0 | 4 |
| New Mexico | 364 | 518 | 574 | 640 | 415 | 370 | 352 | 416 | 612 | 560 |
| New York | 1 | 2 | 3 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| North Carolina | 620 | 401 | 655 | 397 | 606 | 304 | 88 | 19 | 110 | 180 |
| Oklahoma | 1 | 34 | 64 | 67 | 52 | 54 | 4 | 18 | 31 | 0 |
| Oregon | 0 | 0 | 1 | 0 | 0 | 0 | 12 | 131 | 89 | 21 |
| South Carolina | 70 | 115 | 33 | 172 | 179 | 94 | 44 | 125 | 89 | 224 |
| Tennessee | 173 | 55 | 184 | 68 | 40 | 42 | 1 | 7 | 20 | 0 |
| Texas | 387 | 416 | 469 | 490 | 242 | 241 | 176 | 355 | 715 | 571 |
| Utah | 0 | 1 | 2 | 10 | 0 | 0 | 17 | 27 | 123 | 163 |
| Virginia | 3 | 23 | 30 | 19 | 23 | 4 | 2 | 5 | 11 | 9 |
| Washington | 207 | 298 | 221 | 145 | 239 | 244 | 381 | 277 | 150 | 105 |
| West Virginia | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total | 24,771 | 28,929 | 30,165 | 26,940 | 30,241 | 28,975 | 28,148 | 23,827 | 24,375 | 17,215 |

[1] In shipment statistics for California, "northern district" is roughly the area north of San Francisco and Stockton; "central district" is between northern district and a southern boundary roughly defined by a line from Santa Barbara through Mojave; "southern district" is south of central district but exclusive of Imperial Valley.

[2] Not segregated by districts in 1923 reports.

The Imperial Valley is by far the most important cantaloup-shipping district in the United States. Its car-lot shipments have in many years about equaled those from all other States. Central California, or the area south of San Francisco and Stockton and north of a line through Santa Barbara and Mojave, is the source of a large volume of shipments. The crop of Arizona showed an upward trend from 1923 until 1930 when 5,400 cars of cantaloups were marketed; then came a decline in 1931 and 1932. The Colorado shipments reached a peak for the 10-year period in 1926 with about 3,600 cars. In Michigan, Indiana, and Maryland, the decline in rail shipments during the decade beginning in 1923 was due chiefly to the increase in motor-truck shipments.

Honey Dew, Honey Ball, casaba, and Persian melons, are shipped from a number of States, but nearly all of the commercial movement

originates in the Imperial Valley and central California, Arizona, and Colorado (table 3). California alone in recent years has made approximately 90 percent of all such shipments. Car lots of miscellaneous melons increased from less than 1,200 in 1923 to more than 12,000 in both 1930 and 1931. The 1930–32 average shipments of miscellaneous melons (including some cantaloups in mixed carloads) were approximately 11,000 cars which is about one half of the average shipments of cantaloups for the period.

TABLE 3.—*Car-lot shipments of miscellaneous melons* [1] *by States or districts, 1923–32*

| State or district of origin | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| Alabama | 0 | 0 | 0 | 2 | 17 | 1 | 0 | 0 | 0 | 0 |
| Arizona | 0 | 281 | 776 | 566 | 577 | 677 | 294 | 398 | 81 | 89 |
| Arkansas | 0 | 0 | 0 | 0 | 4 | 8 | 0 | 0 | 0 | 0 |
| California [2] | [3] 1,037 | | | | | | | | | |
| Northern district | | 1 | 37 | 7 | 0 | 27 | 189 | 216 | 186 | 319 |
| Southern district | | 0 | 7 | 0 | 5 | 0 | 0 | 0 | 2 | 0 |
| Central district | | 1,463 | 1,594 | 1,942 | 2,045 | 3,456 | 4,008 | 3,353 | 2,080 | 1,961 |
| Imperial Valley | | 174 | 573 | 2,360 | 2,682 | 4,747 | 5,916 | 7,020 | 8,745 | 5,922 |
| Colorado | 111 | 575 | 613 | 1,534 | 985 | 679 | 1,469 | 1,334 | 1,057 | 790 |
| Florida | 0 | 0 | 3 | 0 | 69 | 3 | 0 | 0 | 0 | 0 |
| Georgia | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 2 |
| Idaho | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 |
| Illinois | 0 | 0 | 1 | 0 | 7 | 1 | 0 | 0 | 0 | 0 |
| Indiana | 0 | 0 | 2 | 34 | 50 | 6 | 2 | 12 | 0 | 0 |
| Iowa | 0 | 0 | 0 | 0 | 48 | 75 | 10 | 2 | 1 | 0 |
| Kansas | 3 | 30 | 19 | 1 | 0 | 3 | 1 | 1 | 8 | 9 |
| Michigan | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 |
| Mississippi | 0 | 0 | 0 | 0 | 6 | 18 | 0 | 0 | 0 | 0 |
| Missouri | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 3 | 0 | 0 |
| North Carolina | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 |
| Oregon | 0 | 0 | 0 | 1 | 4 | 0 | 2 | 5 | 1 | 0 |
| South Carolina | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| Texas | 0 | 40 | 29 | 24 | 0 | 3 | 0 | 3 | 43 | 12 |
| Utah | 0 | 0 | 0 | 3 | 0 | 1 | 0 | 0 | 0 | 3 |
| Washington | 0 | 0 | 0 | 0 | 13 | 14 | 1 | 5 | 0 | 0 |
| Total | 1,152 | 2,565 | 3,654 | 6,484 | 6,516 | 9,719 | 11,894 | 12,352 | 12,207 | 9,107 |

[1] Includes casaba, Honey Ball, Honey Dew, and Persian melons (and mixed melons reported since 1930. See footnote 2, table 4), but not watermelons or cantaloups.
[2] See footnote 1, table 2.
[3] Not segregated by districts in 1923 reports.

As an average for the 3 years, 1930–32, about 56 percent of the Honey Dew shipments came from the Imperial Valley. Central California and Colorado are also important sources of supply. Honey Dew shipments exceeded 6,000 cars in both 1930 and 1931 (table 4).

The Imperial Valley is by far the most important source of Honey Ball melons. In the period 1930–32 this district furnished nearly 95 percent of the total supply, which averaged slightly under 2,400 cars per year for the period (table 4).

The car-lot shipments of casaba melons totaled only 155 in 1930 and did not reach this figure in 1931 or 1932. Nearly all the casaba shipments are from the Imperial Valley and the central district of California.

Total shipments of Persian melons, most of which come from the central California district, were slightly more than 400 cars in 1931, but only 161 cars in 1932 (table 4).

TABLE 4.—*Car-lot shipments of casaba, Honey Ball, Honey Dew, Persian, and mixed melons by States or districts, 1930–32* [1]

| State or district of origin | Casaba | | | Honey Ball | | | Honey Dew | | | Persian | | | Mixed [2] | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1930 | 1931 | 1932 | 1930 | 1931 | 1932 | 1930 | 1931 | 1932 | 1930 | 1931 | 1932 | 1930 | 1931 | 1932 |
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| Arizona | 0 | 0 | 0 | 46 | 4 | 39 | 225 | 35 | 15 | 0 | 0 | 0 | 127 | 42 | 35 |
| California: [3] | | | | | | | | | | | | | | | |
| Northern district | 22 | 1 | 1 | 12 | 0 | 3 | 182 | 157 | 315 | 0 | 0 | 0 | 0 | 28 | 0 |
| Southern district | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Central district | 97 | 85 | 98 | 137 | 62 | 75 | 1,665 | 1,155 | 1,174 | 333 | 394 | 161 | 1,121 | 384 | 453 |
| Imperial Valley | 32 | 43 | 33 | 2,401 | 2,665 | 1,646 | 2,873 | 4,201 | 2,745 | 10 | 31 | 0 | 1,704 | 1,805 | 1,498 |
| Colorado | 0 | 0 | 0 | 0 | 9 | 0 | 1,156 | 785 | 677 | 0 | 1 | 0 | 178 | 262 | 113 |
| Georgia | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |
| Indiana | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 12 | 0 | 0 |
| Iowa | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 1 | 0 |
| Kansas | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 8 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| Missouri | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| Oregon | 4 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| Texas | 0 | 3 | 0 | 0 | 10 | 0 | 3 | 19 | 11 | 0 | 2 | 0 | 0 | 9 | 1 |
| Utah | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 |
| Washington | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 |
| Total | 155 | 135 | 132 | 2,596 | 2,750 | 1,764 | 6,105 | 6,362 | 4,946 | 343 | 428 | 161 | 3,153 | 2,532 | 2,104 |

[1] Shipments of these melons were not reported separately prior to 1930.
[2] The term "mixed melons" refers to cars loaded with two or more kinds of melons including cantaloups and any other kinds of muskmelons.
[3] See footnote 1, table 2.

## SHIPPING SEASONS

Competition among various producing districts is influenced not only by the quantity produced and the markets to which the crop is shipped, but also by the time in which the crop is moved to market.

The time of ripening of cantaloups and other melons varies with seasonal conditions from year to year. For instance, the time when the cantaloup movement from Imperial Valley reached 5 cars or more daily varied in the period 1928–32 from May 1 in 1930 to May 15 in 1929. The date of peak shipments was as early as May 22 in 1930 and as late as June 18 in 1928 (table 5). Other cantaloup districts show similar variations.

TABLE 5.—*Period of car-lot movement of cantaloups from specified States or districts, 1928–32*

| State or district | Year | Date of first car-lot shipment | First date on which as many as 5 cars were shipped | Date of peak shipment and number of cars shipped that day | | Date on which shipments fell to 5 cars or less | Date of last shipment |
|---|---|---|---|---|---|---|---|
| | | | | *Date* | *Cars* | | |
| California, Imperial Valley | 1928 | May 3 | May 7 | June 18 | 400 | July 15 | Aug. 17 |
| | [1] 1929 | May 11 | May 15 | June 16 | 423 | July 26 | July 30 |
| | [1] 1930 | Apr. 25 | May 1 | May 22 | 463 | July 16 | Aug. 12 |
| | [1] 1931 | Apr. 18 | May 2 | May 25 | 380 | July 9 | July 22 |
| | [1] 1932 | May 1 | May 8 | June 7 | 273 | July 11 | July 18 |
| Arizona | 1928 | May 16 | June 11 | July 9 | 306 | July 26 | Aug. 31 |
| | 1929 | May 27 | June 18 | July 16 | 239 | Aug. 6 | Aug. 21 |
| | 1930 | May 21 | June 2 | July 3 | 315 | July 28 | July 30 |
| | 1931 | June 8 | June 12 | June 27 | 279 | July 20 | July 22 |
| | 1932 | June 2 | June 8 | June 30 | 192 | July 23 | July 26 |
| Texas | 1928 | May 16 | July 21 | Aug. 1 | 14 | Aug. 11 | Aug. 31 |
| | 1929 | May 18 | June 12 | Aug. 3 | 8 | Aug. 4 | Sept. 6 |
| | 1930 | May 21 | July 18 | July 26 | 17 | Aug. 3 | Sept. 25 |
| | 1931 | June 19 | July 7 | July 22 | 41 | do | Oct. 16 |
| | 1932 | June 15 | July 13 | Aug. 4 | 35 | Aug. 12 | Oct. 5 |

[1] Does not include records of autumn shipments as follows: 92 cars, Oct. 5–Nov. 8, 1929; 50 cars, Oct. 9–31, 1930; 20 cars, Oct. 15–18, 1931; 29 cars, Oct. 3–20, 1932.

TABLE 5.—*Period of car-lot movement of cantaloups from specified States of districts, 1928–32*—Continued

| State or district | Year | Date of first car-lot shipment | First date on which as many as 5 cars were shipped | Date of peak shipment and number of cars shipped that day | | Date on which shipments fell to 5 cars or less | Date of last shipment |
|---|---|---|---|---|---|---|---|
| | | | | *Date* | *Cars* | | |
| South Carolina | 1928 | June 30 | July 7 | July 14 | 10 | July 16 | Aug. 4 |
| | 1929 | June 17 | June 24 | June 24 | 10 | June 25 | July 6 |
| | 1930 | June 20 | June 27 | July 5 | 17 | July 9 | July 11 |
| | 1931 | June 27 | June 29 | July 3 | 9 | July 6 | July 18 |
| | 1932 | June 21 | June 24 | June 28 | 34 | July 9 | July 15 |
| California, central district | 1928 | June 19 | June 29 | July 25 | 175 | Aug. 21 | Oct. 17 |
| | 1929 | July 5 | July 16 | Aug. 8 | 94 | Aug. 22 | Oct. 14 |
| | 1930 | June 27 | July 1 | July 24 | 91 | Aug. 20 | Aug. 26 |
| | 1931 | June 15 | June 22 | July 8 | 142 | Aug. 2 | Sept. 28 |
| | 1932 | June 25 | June 28 | July 21 | 80 | Aug. 8 | Oct. 2 |
| North Carolina | 1928 | July 14 | July 17 | July 23 | 37 | Aug. 1 | Aug. 10 |
| | 1929 | July 15 | July 18 | July 30 | 9 | July 31 | Aug. 3 |
| | 1930 | July 11 | ---------- | July 15 | 4 | ---------- | July 23 |
| | 1931 | July 10 | July 11 | July 18 | 15 | July 19 | Aug. 4 |
| | 1932 | June 30 | ---do----- | July 15 | 26 | July 21 | July 29 |
| Arkansas | 1928 | July 13 | July 15 | July 21 | 78 | Aug. 7 | Aug. 29 |
| | 1929 | July 5 | July 12 | July 18 | 54 | July 28 | Aug. 17 |
| | 1930 | July 2 | July 7 | July 14 | 18 | July 20 | Aug. 21 |
| | 1931 | July 10 | July 13 | July 20 | 36 | July 26 | Do. |
| | 1932 | July 6 | July 7 | July 16 | 68 | July 23 | Aug. 6 |
| New Mexico | 1928 | July 16 | July 21 | Aug. 9 | 17 | Aug. 25 | Aug. 31 |
| | 1929 | July 19 | July 19 | Aug. 6 | 20 | Aug. 21 | Aug. 24 |
| | 1930 | July 14 | July 21 | Aug. 5 | 30 | Aug. 10 | Aug. 19 |
| | 1931 | ---do----- | July 15 | Aug. 6 | 37 | ---do----- | Aug. 16 |
| | 1932 | July 15 | ---do----- | Aug. 5 | 43 | Aug. 13 | Sept. 1 |
| Indiana | 1928 | July 28 | July 29 | Aug. 7 | 42 | Aug. 19 | Aug. 29 |
| | 1929 | July 25 | July 26 | Aug. 9 | 25 | Aug. 18 | Aug. 31 |
| | 1930 | July 23 | July 23 | July 29 | 36 | Aug. 2 | Sept. 6 |
| | 1931 | ---do----- | July 30 | Aug. 3 | 30 | Aug. 9 | Sept. 5 |
| | 1932 | July 18 | July 18 | July 23 | 36 | July 30 | Aug. 26 |
| Maryland, Eastern Shore | 1928 | July 27 | July 27 | Aug. 21 | 66 | Aug. 29 | Sept. 5 |
| | 1929 | July 23 | July 23 | Aug. 1 | 44 | Aug. 19 | Sept. 7 |
| | 1930 | July 21 | July 24 | Aug. 11 | 25 | Aug. 15 | Sept. 15 |
| | 1931 | July 25 | July 25 | Aug. 4 | 33 | Aug. 17 | Aug. 22 |
| | 1932 | ---do----- | July 29 | Aug. 16 | 19 | Aug. 22 | Sept. 3 |
| Delaware | 1928 | Aug. 1 | Aug. 3 | Aug. 8 | 37 | Aug. 28 | Aug. 29 |
| | 1929 | July 30 | July 31 | Aug. 3 | 34 | Aug. 20 | Aug. 28 |
| | 1930 | July 15 | Aug. 1 | Aug. 9 | 22 | Aug. 14 | Sept. 11 |
| | 1931 | July 27 | July 28 | Aug. 1 | 23 | Aug. 19 | Aug. 26 |
| | 1932 | July 29 | July 30 | Aug. 9 | 21 | Aug. 17 | Aug. 27 |
| Washington | 1928 | July 23 | ---do----- | Aug. 8 | 18 | Aug. 14 | Oct. 12 |
| | 1929 | July 30 | Aug. 5 | Aug. 12 | 26 | Aug. 17 | Oct. 7 |
| | 1930 | July 26 | Aug. 2 | Aug. 18 | 21 | Aug. 27 | Sept. 24 |
| | 1931 | July 27 | July 31 | Aug. 3 | 11 | Aug. 7 | Sept. 15 |
| | 1932 | July 25 | July 25 | Aug. 8 | 12 | Aug. 12 | Sept. 14 |
| Colorado | 1928 | Aug. 18 | Aug. 20 | Sept. 5 | 107 | Sept. 30 | Oct. 12 |
| | 1929 | Aug. 8 | Aug. 8 | Sept. 4 | 143 | Sept. 29 | Oct. 5 |
| | 1930 | Aug. 5 | Aug. 6 | Sept. 2 | 132 | Sept. 15 | Oct. 6 |
| | 1931 | Aug. 11 | Aug. 11 | Aug. 25 | 92 | Sept. 27 | Oct. 16 |
| | 1932 | Aug. 5 | Aug. 8 | Aug. 31 | 63 | Sept. 23 | Oct. 8 |

Honey Dew melons usually ripen from 3 to 4 weeks later and the season continues later than that of cantaloups from the same district (tables 5 and 6). Honey Ball, casaba, and Persian melons also do not move to market until the cantaloup season is well under way (table 7).

A picture of the competition among States or districts in time and volume of movement to market is obtained by a tabulation of the weekly shipments. The situation as to cantaloups in 1932 is shown in table 8. Truck-shipment figures are included when available. There is considerable variation from year to year in the competition among producing districts as to both volume and time of movement.

TABLE 6.—*Period of car-lot movement of Honey Dew melons from specified States, or districts, 1930–32*

| State or district | Year | Date of first car-lot shipment | First date on which as many as 5 cars were shipped | Date of peak shipment and number of cars shipped that day | | Date on which shipments fell to 5 cars or less | Date of last shipment |
|---|---|---|---|---|---|---|---|
| | | | | *Date* | *Cars* | | |
| California, Imperial Valley | [1] 1930 | May 19 | June 2 | June 14 | 83 | Aug. 14 | Aug. 25 |
| | [1] 1931 | May 13 | May 25 | July 7 | 119 | July 31 | Aug. 26 |
| | [1] 1932 | May 23 | May 31 | July 11 | 100 | Aug. 8 | Aug. 9 |
| Arizona | 1930 | June 10 | July 25 | Aug. 5 | 22 | Aug. 7 | Sept. 11 |
| | 1931 | July 3 | ---------- | July 24 | 3 | ---------- | Aug. 1 |
| | 1932 | July 6 | ---------- | July 21 | 2 | ---------- | Aug. 14 |
| California, Central district | 1930 | July 23 | July 29 | Aug. 11 | 59 | Aug. 31 | Nov. 1 |
| | 1931 | July 11 | July 20 | July 27 | 41 | Aug. 2 | Nov. 10 |
| | 1932 | July 28 | Aug. 2 | Aug. 24 | 42 | Sept. 18 | Dec. 10 |
| Northern district | 1930 | Aug. 11 | Aug. 25 | Sept. 8 | 17 | Sept. 12 | Oct. 16 |
| | 1931 | July 25 | Aug. 29 | Sept. 3 | 9 | Sept. 4 | Oct. 2 |
| | 1932 | Aug. 11 | Aug. 15 | Aug. 23 | 14 | Aug. 28 | Nov. 2 |
| Colorado | 1930 | Aug. 23 | Sept. 3 | Sept. 12 | 68 | Sept. 14 | Oct. 16 |
| | 1931 | Aug. 28 | Aug. 30 | Sept. 8 | 43 | Oct. 4 | Oct. 17 |
| | 1932 | Aug. 21 | ---do---- | Sept. 9 | 32 | Sept. 18 | Oct. 11 |

[1] Does not include shipments in October and November as follows: 1930, 212 cars; 1931, 143 cars; 1932, 186 cars.

TABLE 7.—*Period of car-lot movement of Honey Ball, casaba, and Perisan melons from specified districts, 1930–32*

HONEY BALL MELONS

| Shipping districts in California | Year | Date of first car-lot shipment | Date of peak shipment and number of cars shipped that day | | Date of last shipment |
|---|---|---|---|---|---|
| | | | *Date* | *Cars* | |
| Imperial Valley | [1] 1930 | June 7 | July 29 | 85 | Aug. 25 |
| | [1] 1931 | May 29 | July 7 | 111 | Aug. 10 |
| | 1932 | May 30 | July 5 | 80 | Aug. 17 |
| Central district | 1930 | July 22 | Sept. 2 | 11 | Oct. 3 |
| | 1931 | July 23 | July 30 | 4 | Sept. 27 |
| | 1932 | July 26 | Sept. 3 | 6 | Oct. 11 |

CASABA MELONS

| | | | | | |
|---|---|---|---|---|---|
| Imperial Valley | 1930 | June 17 | July 17 | 4 | Aug. 7 |
| | 1931 | June 16 | June 27 | 4 | Do. |
| | 1932 | June 9 | June 22 | 3 | July 30 |
| Central district | 1930 | July 31 | Oct. 6 | 6 | Dec. 3 |
| | 1931 | July 7 | July 20 | 3 | Nov. 25 |
| | 1932 | July 25 | Oct. 18 | 5 | Dec. 10 |

PERSIAN MELONS

| | | | | | |
|---|---|---|---|---|---|
| Imperial Valley | 1930 | June 21 | July 3 | 2 | July 8 |
| | 1931 | June 30 | July 1 | 6 | Do. |
| | 1932 | ---------- | ---------- | ---------- | ---------- |
| Central district | 1930 | July 19 | Sept. 5 | 10 | Oct. 18 |
| | 1931 | July 18 | July 31 | 18 | Oct. 24 |
| | 1932 | Aug. 1 | Aug. 23 | 7 | Oct. 29 |

[1] Does not include shipments in September, October, and November as follows: 1930, 13 cars; 1931, 17 cars.

TABLE 8.—*Car-lot shipments of cantaloups by States or districts and by weeks, 1932*

| State or district of origin | Shipments for week beginning— | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May 1 | May 8 | May 15 | May 22 | May 29 | June 5 | June 12 | June 19 | June 26 | July 3 | July 10 | July 17 | July 24 | July 31 | Aug. 7 | Aug. 14 | Aug. 21 | Aug. 28 | Sept. 4 | Sept. 11 | Sept. 18 | Sept. 25 | Oct. 2 | Oct. 9–Oct. 23 | Total cars |
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| California, Imperial Valley | 14 | 178 | 888 | 1, 209 | 1, 232 | 1, 322 | 1, 053 | 840 | 700 | 107 | 19 | 1 | | | | | | | | | | | 20 | 9 | 7, 592 |
| Arizona | | | | | 2 | 50 | 114 | 259 | 1, 076 | 803 | 587 | 120 | 5 | | | | | | | | | | | 4 | 3, 020 |
| Louisiana | | | | | 1 | | | | 1 | 13 | 11 | | | | | | | | | | | | | | 26 |
| Florida | | | | | | 13 | | | | | | | | | | | | | | | | | | | 13 |
| Texas | | | | | | | 2 | 2 | 5 | 6 | 28 | 107 | 99 | 162 | 58 | 27 | 43 | 8 | 2 | 6 | 11 | 3 | 2 | | 571 |
| Georgia | | | | | | | 5 | 38 | 32 | 5 | 1 | | | | | | | | | | | | | | 81 |
| South Carolina | | | | | | | | 19 | 123 | 70 | 12 | | | | | | | | | | | | | | 224 |
| California, central district [1] | | | | | | | | 1 | 44 | 92 | 223 | 476 | 358 | 190 | 26 | 23 | 6 | 1 | 2 | 12 | 5 | 1 | 1 | | 1, 461 |
| North Carolina | | | | | | | | | 1 | 3 | 105 | 62 | 9 | | | | | | | | | | | | 180 |
| Arkansas | | | | | | | | | | 53 | 323 | 104 | 51 | 10 | | | | | | | | | | | 541 |
| Nevada | | | | | | | | | | 5 | 8 | 20 | 3 | 3 | | | 2 | 5 | 11 | 6 | 1 | | | | 64 |
| New Mexico | | | | | | | | | | | 10 | 85 | 97 | 201 | 137 | 25 | 2 | 3 | | | | | | | 560 |
| Missouri | | | | | | | | | | | 4 | 3 | 6 | 1 | | | | | | | | | | | 14 |
| California, southern district [1] | | | | | | | | | | | 3 | 5 | | 1 | | | | | | | | | | | 9 |
| Indiana | | | | | | | | | | | | 74 | 116 | 35 | 10 | 1 | 3 | | | | | | | | 239 |
| Illinois | | | | | | | | | | | | 7 | 20 | 11 | 4 | 3 | | | | | | | | | 45 |
| Virginia, Norfolk district | | | | | | | | | | | | 4 | 2 | | | | | | | | | | | | 6 |
| Maryland, Eastern Shore district [2] | | | | | | | | | | | | | 110 | 343 | 432 | 458 | 246 | 133 | 19 | | | | | | 1, 741 |
| Delaware [2] | | | | | | | | | | | | | 58 | 231 | 365 | 238 | 72 | 29 | 5 | | | | | | 998 |
| Washington | | | | | | | | | | | | | 10 | 41 | 35 | 10 | 4 | 3 | 1 | 1 | | | | | 105 |
| Virginia, other than Norfolk district [2] | | | | | | | | | | | | | 3 | 2 | 3 | | | | | | | | | | 8 |
| Kansas | | | | | | | | | | | | | 2 | 2 | | | | | | | | | | | 4 |
| California, northern district [1] | | | | | | | | | | | | | 1 | 2 | 2 | | | | | | | | | | 5 |
| Maryland, other than Eastern Shore district | | | | | | | | | | | | | 1 | | 1 | | | 1 | | | | | | | 3 |
| Colorado | | | | | | | | | | | | | | 4 | 211 | 177 | 328 | 328 | 294 | 263 | 94 | 32 | 34 | | 1, 765 |
| Iowa | | | | | | | | | | | | | | 1 | 3 | 7 | 10 | 5 | | | | | | | 26 |
| Michigan [3] | | | | | | | | | | | | | | 1 | 5 | 6 | 1 | | | | | | | | 13 |
| Oregon | | | | | | | | | | | | | | | 3 | 3 | | 8 | 4 | 3 | | | | | 21 |
| Idaho | | | | | | | | | | | | | | | 2 | 2 | 2 | | | | | | | | 6 |
| New Jersey [3] | | | | | | | | | | | | | | | 1 | | 3 | | | | | | | | 4 |
| Utah | | | | | | | | | | | | | | | | | 18 | 57 | 33 | 24 | 21 | 9 | 1 | | 163 |
| Total [3] | 14 | 178 | 888 | 1, 209 | 1, 235 | 1, 385 | 1, 174 | 1, 159 | 1, 982 | 1, 157 | 1, 334 | 1, 068 | 951 | 1, 241 | 1, 298 | 980 | 740 | 581 | 371 | 315 | 132 | 45 | 58 | 13 | 19, 508 |

[1] See footnote 1, table 2.
[2] Includes shipments by motor truck.
[3] In addition to car-lot shipments shown for Michigan, New Jersey, and some other States, there was a considerable movement by motor truck, for which records are not available.

In 1932 the Imperial Valley had little competition until the second week in June, when Arizona shipments became a considerable factor. Central California, Arkansas, Texas, and North Carolina were important sources of supply in July. New Mexico, Indiana, Maryland, and Delaware began shipping in quantity the latter part of July. Colorado was the most important late shipping State. Most of the movement from this State was in August and September.

The peak week of the 1932 marketing season was the 7-day period beginning June 26, when shipments for the entire country totaled 1,982 cars. Heavy shipments were made from Arizona and Imperial Valley in this week, and several other States contributed to the total movement. In the preceding week, 1,159 cars were shipped and in the following week, 1,157 cars. The greatest number of States, 16, were shipping during the week beginning July 31. Cantaloup shipments exceeded 100 cars per week from May 8 to September 24 (table 8).

The Honey Dew crop of the Imperial Valley does not compete seriously with that of central or northern California or Colorado. In 1932 most of the Imperial Valley Honey Dew crop had moved by the first week in August, when the shipments from the central district of California became heavy (table 9). In some seasons, however, there is somewhat more overlapping. In 1932, Honey Dews were shipped at the rate of 100 cars or more per week for about 4 months, from June 5 to October 8, excepting only the week beginning August 7, when 89 cars were shipped.

TABLE 9.—*Car-lot shipments of Honey Dew melons by States or districts and by weeks, 1932*

| State or district of origin | Shipments for week beginning— | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | May 22 | May 29 | June 5 | June 12 | June 19 | June 26 | July 3 | July 10 | July 17 | July 24 | July 31 | Aug. 7 | Aug. 14 |
| California, Imperial Valley | *Cars* 2 | *Cars* 36 | *Cars* 121 | *Cars* 264 | *Cars* 215 | *Cars* 299 | *Cars* 468 | *Cars* 576 | *Cars* 290 | *Cars* 185 | *Cars* 101 | *Cars* 2 | *Cars* 76 |
| Arizona | | | | | | | 2 | 3 | 7 | | 1 | 1 | 1 |
| California: | | | | | | | | | | | | | |
| Central district [1] | | | | | | | | | | 5 | 25 | 82 | 182 |
| Northern district [1] | | | | | | | | | | | | 3 | 24 |
| Texas | | | | | | | | | | | | 1 | 5 |
| Colorado | | | | | | | | | | | | | |
| Kansas | | | | | | | | | | | | | |
| Total | 2 | 36 | 121 | 264 | 215 | 299 | 470 | 579 | 297 | 190 | 127 | 89 | 288 |

| State or district of origin | Shipments for week beginning— | | | | | | | | | | | Total cars |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Aug. 21 | Aug. 28 | Sept. 4 | Sept. 11 | Sept. 18 | Sept. 25 | Oct. 2 | Oct. 9 | Oct. 16 | Oct. 23 | Oct. 30–Dec. 4 | |
| California, Imperial Valley | *Cars* 85 | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* 4 | *Cars* 15 | *Cars* 6 | *Cars* | *Cars* 2,745 |
| Arizona | | | | | | | | | | | | 15 |
| California: | | | | | | | | | | | | |
| Central district [1] | 174 | 182 | 133 | 64 | 51 | 80 | 65 | 36 | 34 | 27 | 34 | 1,174 |
| Northern district [1] | 62 | 60 | 47 | 33 | 14 | 13 | 34 | 14 | 6 | 4 | 1 | 315 |
| Texas | 5 | | | | | | | | | | | 11 |
| Colorado | 12 | 33 | 150 | 149 | 93 | 143 | 84 | 13 | | | | 677 |
| Kansas | | | | | 6 | 2 | 1 | | | | | 9 |
| Total | 338 | 275 | 330 | 246 | 164 | 238 | 184 | 67 | 55 | 37 | 35 | 4,946 |

[1] See footnote 1, table 2.

The movement of Honey Ball melons in 1932 exceeded 100 cars each week from June 12 to July 30 with the exception of the week beginning June 19. The peak movement was for the week beginning July 3 with 430 cars (table 10). The Imperial Valley does not have serious competition from other districts in marketing its crop of Honey Ball melons.

TABLE 10.—*Car-lot shipments of Honey Ball melons by States or districts and by weeks, 1932*

| State or district of origin | Shipments for week beginning— | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | May 29 | June 5 | June 12 | June 19 | June 26 | July 3 | July 10 | July 17 | July 24 | July 31 | Aug. 7 |
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| California, Imperial Valley | 4 | 14 | 108 | 82 | 263 | 429 | 357 | 206 | 121 | 42 | 17 |
| Georgia | | | | | | 1 | | | | | |
| Arizona | | | | | | | | 1 | 16 | 10 | 8 |
| California: Central district [1] | | | | | | | | | 4 | 1 | 2 |
| Total | 4 | 14 | 108 | 82 | 263 | 430 | 357 | 207 | 141 | 53 | 27 |

| State or district of origin | Shipments for week beginning— | | | | | | | | | Total cars |
|---|---|---|---|---|---|---|---|---|---|---|
| | Aug. 14 | Aug. 21 | Aug. 28 | Sept. 4 | Sept. 11 | Sept. 18 | Sept. 25 | Oct. 2 | Oct. 9 | |
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| California, Imperial Valley | 3 | | | | | | | | | 1,646 |
| Georgia | | | | | | | | | | 1 |
| Arizona | 3 | 1 | | | | | | | | 39 |
| California: | | | | | | | | | | |
| Central district [1] | 5 | 15 | 18 | 16 | 2 | 3 | 5 | 3 | 1 | 75 |
| Northern district [1] | | | | 1 | 1 | 1 | | | | 3 |
| Total | 11 | 16 | 18 | 17 | 3 | 4 | 5 | 3 | 1 | 1,764 |

[1] See footnote 1, table 2.

There is considerable overlapping between the cantaloup marketing season and the Honey Dew and Honey Ball season, although the latter crops are not ready for shipment as early in the season as are cantaloups. In 1932 the largest total weekly shipments of cantaloups, Honey Ball, and Honey Dew melons respectively were in successive weeks beginning June 26.

## PREPARING THE CROP FOR MARKET

### IMPORTANCE OF GRADE, CONDITION, AND PACK

A large part of the cantaloups which arrive on the markets each year are too immature to be palatable. As a result, many consumers are prejudiced against cantaloups and the demand is impaired. There is often a pronounced lack of uniformity in quality and condition of the melons in a crate. Some may be immature and others overripe. If the consumers could obtain cantaloups of uniformly good quality and condition, it is probable that the demand would increase notably.

Cantaloups that are immature, overripe, or otherwise defective are a source of dissatisfaction among consumers and handlers on the market. The shipment of such stock often results in severe losses

to growers and shippers. There is much room for improvement in the average quality and pack of cantaloups.

Efforts are being made, particularly in Western States, to develop better varieties for shipping and to improve the quality of melons on the markets by shipping considerable quantities that have been vine ripened and precooled. Laws have been enacted in some States providing that cantaloups must meet certain grade requirements before they can be shipped to market.

On the New York City market during 3 months of the 1932 season, cantaloups of inferior quality or poor condition were mentioned, or quoted separately at a discount, in the Federal market news reports, approximately 40 percent of the time. The discount ranged generally from 50 cents to $1.25 per standard or jumbo crate. The range in price of good stock during most of this period was about $2.50 to $4 per crate. In the leading markets, vine-ripened and precooled stock frequently brought a premium of 25 cents to $1.50 per standard or jumbo crate in 1932, over supplies that were harvested and handled under the usual methods.

A great deal of knowledge and care is necessary in so harvesting, grading, packing, and shipping cantaloups that they will arrive on the market in good condition. It is to the advantage of growers and shippers generally to build up and maintain the confidence of dealers and consumers through correct methods of preparing the crop for market.

### HARVESTING CANTALOUPS

It is difficult to give a definite rule for determing when cantaloups are ready to be picked. The indications of the correct stage for picking vary somewhat with the variety, seasonal conditions, district where grown, method of handling and shipping, and probable time during which the fruit will not be protected by refrigeration.

Sound cantaloups that have ripened on the vines are of better flavor and texture than those that have been picked when green or semiripe. Cantaloups that are picked when immature, may eventually get soft, but the quality never approaches that of vine-ripened fruit. It has been the general practice to pick melons before they are fully ripe, so they will not be soft or overripe when they reach the retailer or consumer. In recent years, however, the practice of allowing the cantaloups to reach a "hard ripe" stage on the vines in western producing areas and precooling them before shipping has met with considerable success. These vine-ripened, precooled cantaloups have usually brought a premium on the markets. When delivery to the retailer or consumer will be made within approximately 1 day after picking, as is often the case with motor-truck shipments, the cantaloups can usually be allowed to ripen on the vines. Even in shipments to eastern markets from the West, if cantaloups are handled promptly and under the best methods, they can be allowed to reach a fairly ripe stage on the vine and still not be soft when they reach the retailer.

In picking, the growers and shippers should have in mind the desirability of having the cantaloups practically ripe when they reach the consumer. If picking is delayed too long there is the certainty of loss owing to soft and overripe stock, whereas if the cantaloups are picked too soon their poor quality is likely to cause dissatisfaction on

the part of consumers. By keeping in communication with dealers in the markets, growers and shippers can ascertain whether their shipments are arriving in good condition.

Various tests or observations aid pickers and field inspectors in selecting the melons that are ready to be picked. Some of the general indications of maturity by which pickers are guided in harvesting cantaloups include the appearance of the netting, color of the rind, condition of blossom end of the melon, and ease of separation from the vine. The grower or field man usually cuts and tastes a few melons in the field. An indication of maturity is the disappearance of the arils or coverings that surround the seeds during their development. The seeds then become slightly loosened from the jellylike substance that surrounds them.

The netting of an immature cantaloup is flat and creased on the top; this netting rounds out, hardens, and assumes a whitish color as the fruit ripens. The "crown-set" melons which are the first to mature usually develop more rounded netting than do the melons which form later on the same vine. The dull-green color of the skin which shows through the openings in the netting usually turns to a uniformly lighter shade of green and assumes a yellowish tint as the melon ripens. As the cantaloup approaches maturity, slight radial cracks known as sugar cracks appear around the blossom end which begins to soften.

A frequently used field test of maturity is the ease with which the stem separates from the melon. The "full-slip" stage indicates that the cantaloup is practically ripe. The stem can be loosened by a slight pressure of the thumb, leaving a smooth scar on the cantaloup (fig. 2). The "half-slip" stage means that full maturity has not been reached but that the stem can be loosened by pressure of the thumb leaving a scar, part of which is rough or has a piece of the stem adhering (fig. 3). There has been some tendency in recent years to allow the crown-set melons to reach or approach the full-slip stage before picking them even when they are to be shipped under ordinary methods. Experience has shown that a full-slip crown-set cantaloup will carry to market in better condition than a full-slip cantaloup of a later set.

The usual practice in harvesting has been to pick the cantaloups before they have ripened on the vine. This commercial stage is indicated by the loosening of the seeds from the jellylike substance surrounding them; by a well-rounded, white netting on at least a part of the surface of the cantaloup; by a uniform greenish ground color of the skin showing through the netting; by a slight softening at the blossom end and the appearance of sugar cracks; and by an approach to the full-slip stage for the crown-set melons, but a half-slip stage for the later set melons.

Under the practice of precooling before shipment, which has become more common in recent years, the melons are allowed to reach a more advanced stage of maturity before they are picked. These vine-ripened cantaloups should be at the full-slip stage, and prompt handling between the field and the refrigerator car is essential. The skin showing through the netting should be turning yellow, but the cantaloup should still be hard or firm, although having a noticeable characteristic odor.

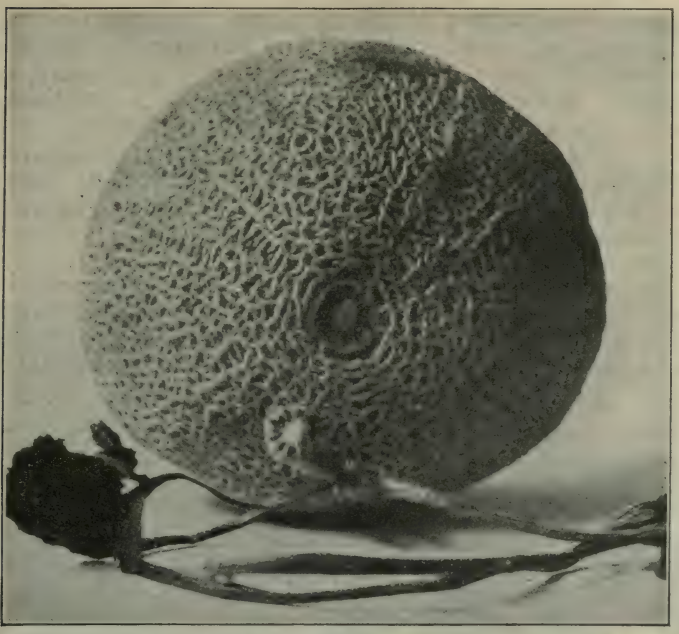

FIGURE 2.—A cantaloup that was picked at "full slip" leaving a clean, cuplike hole where the stem had been attached.

FIGURE 3.—A cantaloup picked at "half slip." Only a part of the stem slipped easily from the melon.

Cantaloups should not be cut from the vines and should not be picked when they are so immature that the stem breaks off a short distance from the melon, as is still the practice in a few districts.

In addition to the general indications of maturity, there are certain tests which are in use to determine the percentage of soluble solids in the juice. The proportion of soluble solids, mostly sugar, increases as the cantaloup matures but is materially influenced by a number of factors, such as variety, weather, condition of the vines, and whether the cantaloup is from the crown set or a later set. (For method of testing for soluble solids see p. 30.)

In many cantaloup-producing districts at the beginning and toward the end of the shipping season, workmen go through the fields every 2 or 3 days to pick the melons that are ready for shipment. During the principal part of the shipping season, in some districts, the fields are picked over practically every day (fig. 4). Rainy, cloudy, or cool

FIGURE 4.—Picking cantaloups in a western field.

weather may retard normal ripening, making advisable some change in the usual picking schedule. When cantaloups are shipped in the vine-ripened stage, the fields must be picked over every day, and in very hot weather twice a day, and grading and handling must be done rapidly. In the Imperial Valley the average field is probably picked over from 10 to 15 times in a season. In other districts, like those in Indiana, Arkansas, and the Carolinas, many fields are picked over from 3 to 10 times during the season. Many growers do much of their picking in the morning before the cantaloups have become heated, or in the evening for shipment by motor truck during the night or for packing the next day.

Cantaloups should be handled carefully in harvesting and packing to avoid bruising or other injury. In the West, picking bags are in general use. The top and bottom of the bag are fastened together with a strap so the bag can be slung over the picker's shoulder. These bags have an opening at the bottom through which the cantaloups

can be conveniently emptied into a container for hauling to the packing shed. In some districts in the East and Middle West, cantaloups are picked in hampers or baskets. In the Northwest burlap sacks are commonly used.

A general practice among pickers is to carry short sticks for parting the leaves of the vine. This saves much stooping to look for cantaloups that are ready for picking.

Standard crates, about 12 by 12 by 22½ inches, are generally used in the West in hauling the cantaloups from the field to the packing

FIGURE 5.—Hauling cantaloups to the packing shed in a western field.

FIGURE 6.—Hauling cantaloups to the packing shed in hampers in an eastern district.

shed. Some growers use a crate of heavier material and slightly different dimensions (fig. 5). The field crates are usually distributed through the field before the picking begins. Hampers and baskets are also used for this purpose in various districts (fig. 6). In some eastern districts, cantaloups are sometimes hauled in sacks or loose in the wagon or truck, but this is an undesirable practice as the melons are likely to be injured by bruising. The trucks used in hauling the cantaloups to the packing sheds in important western districts are sometimes provided with large pieces of canvas to protect the load from dust and the hot sun.

### HARVESTING HONEY DEW AND HONEY BALL MELONS

Honey dew or Honey Ball melons which are to be shipped under ordinary methods (not vine ripened and precooled) are generally considered ready for harvesting when the color of the skin has changed from a dark-green to a light-green or whitish shade, or, under some conditions, to a cream color. At this stage of maturity the melon loses its slightly rough or fuzzy feel and the skin becomes smooth. A slight softening at the blossom end is an indication of approaching maturity, but during the hottest part of the day immature melons may become slightly soft at the blossom end.

Since these appearance tests may vary somewhat under different conditions, it is desirable to cut a number of melons and observe the internal characteristics as a check against the external appearance. If the jellylike substance in which the seeds are embedded has been absorbed by the melon, a desirable stage of maturity has been attained. The test for soluble solids in the juice of the edible portion is sometimes used as a field test in determining when Honey Dew and Honey Ball melons are ready for harvest. Honey dews are usually clipped from the vines, leaving about one half inch of stem attached to the melon.

Some shipments of Honey Dew and Honey Ball are of vine-ripened fruits. Precooling of vine-ripened Honey Dew melons before shipment has not been practiced generally, but vine-ripened Honey Ball melons are frequently precooled. Honey Dew and Honey Ball melons when vine-ripened usually take on a cream or light-yellow shade. Under some conditions, however, the melons may be ripe and still retain a greenish shade. This may occur when the melons are covered with a heavy foilage or under certain conditions of soil and climate. For example, in central California the vine-ripened melons do not usually have as much of a creamy color as is common in the Imperial Valley. When Honey Dew and Honey Ball melons are vine-ripened, they have reached the full-slip stage; there is a softening at the blossom end; the ridges adjacent to the stem end are well rounded out and smooth; and the odor characteristic of a ripe melon is noticeable.

Honey Dew and Honey Ball melons are slower in maturing than cantaloups. In California, fields of these melons are usually picked over about once a week, except during hot weather when it becomes necessary to pick over the fields every 3 or 4 days. In Colorado it is the general practice to make a few pickings of Honey Dew melons that have ripened before the main part of the crop; then when the main part of the crop is ready, all the remaining melons are harvested at one picking. This, of course, results in some lack of uniformity in quality and condition. The greener melons are sometimes allowed to ripen for several days after the picking before being shipped.

In harvesting Honey Dew melons a common practice is to empty the picking bags directly into the truck bed. A wagon instead of a truck is sometimes used in hauling. A plank is frequently attached to the rear of the truck, forming an incline for the pickers' use in walking into the truck to empty their bags. Another practice is to pile the melons in the fields near the roadways ready for loading. A man on the ground usually tosses the melons to a man on the truck. When the melons are hauled, loose straw bedding should be used to prevent bruising. The load should not be deep, as this frequently results in bruising the melons at the bottom of the load.

Honey Dew melons if exposed too long when they are piled in the field may be injured by sunscald. Disturbing the foliage over a Honey Dew melon in the field and leaving it exposed, particularly if it is turned bottom side up, is likely to result in sunscald. Honey Dew melons, when loaded on trucks, should be protected from hot sun and dust by a canvas cover. In Colorado, late in the season, piles of these melons are frequently covered with vines to protect them from freezing until they can be hauled to the packing shed.

FIGURE 7.—A typical packing shed in a western cantaloup field.

FIGURE 8.—Packing cantaloups in a western field shed.

Practically the same harvesting methods are used for Honey Ball melons as for cantaloups.

### PACKING SHEDS

In the West a large part of the packing is done in open sheds located in or near the melon field (fig. 7). These temporary sheds usually are constructed by placing a roof of brush, straw, leaves, or canvas on upright poles. The shed is chiefly to shade the melons and the packers. Melons packed in these temporary sheds are known as "field-pack" melons (fig. 8).

In eastern, southern, and midwestern districts, farm buildings are often used when packing cantaloups. In some instances, packing is done in the shade of a tree or on a railway station platform.

During recent years in important western producing districts, a considerable number of central packing sheds have been constructed (fig. 9). A few of these central sheds are also in use in the eastern and midwestern districts. Western shippers who contract with growers for large acreages, growers' associations, and those who perform the packing operations under contract, generally use a central packing shed located on a railroad spur, so that the packed melons can be loaded directly on the cars. The central sheds are usually of more permanent construction than the field sheds and their output is often referred to as "shed-pack" as contrasted with field-pack stock.

When the central packing shed is used the melons are trucked directly to it in the field crates.

FIGURE 9.—Packing cantaloups in a central packing shed in a western district.

The time required for packing in central sheds is less than in field sheds, and the melons are placed under refrigeration in the car more promptly. There is some advantage in not having to haul the packed crates a considerable distance through the dust and hot sun from the field shed to the refrigerator cars. In a large central shed there is usually a more systematic arrangement of equipment, and packing and grading, which are done by an experienced crew, can be given better supervision than in field sheds, so that a more uniform pack results. When packing is done in a central plant, it is not necessary to haul the crates or crate material from the railroad to the field.

### PACKING EQUIPMENT

When packing is done in field packing sheds or in farm buildings, the equipment usually includes a sorting and packing bin, a bench on

which the crate is placed while it is being packed, and another bench on which the packed crates are placed while the lids are nailed. Roller conveyors are sometimes used for moving the packed crates along to the lidders. The sorting and packing bins should be padded and of convenient height and slope toward the packer so that the melons will be within easy reach.

In the central packing sheds the sorting and packing bins and packing benches are a part of the equipment, and there are usually belt or roller conveyors for moving the packed crates, lidding presses to facilitate nailing on lids, and in a few instances in both western and eastern

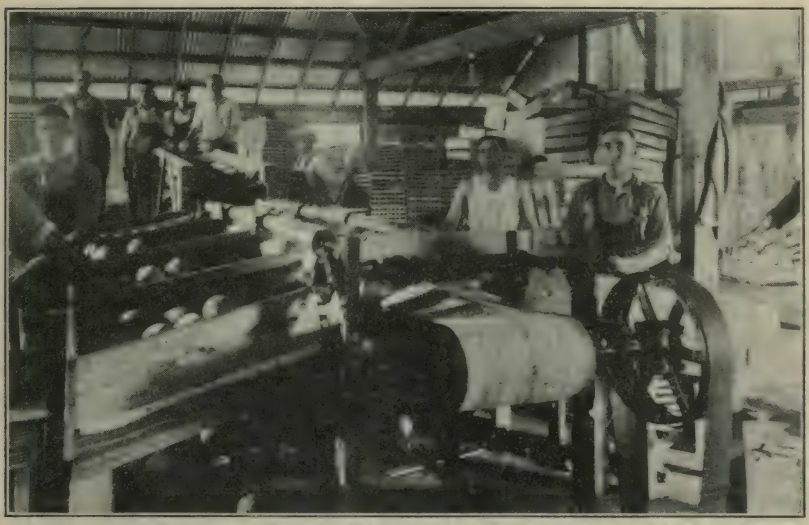

FIGURE 10.—An eastern cantaloup packing shed in which a mechanical device is used for sizing the melons.

districts, sizing machinery, although most of the sizing is done by hand (fig. 10). Vats for washing Honey Dew and Honey Ball melons are a part of the equipment in some central sheds in the West. Machines for brushing these melons as they are being dried are used in some sheds. Machines that brush cantaloups are used in a few packing houses in the eastern districts.

The size of the central shed depends on the quantity of melons to be handled through it. Some central sheds have space for 20 to 40 packers in a line.

### PACKAGES

Slatted crates, of dimensions shown in table 11, are the packages generally used in western States in shipping cantaloups and other muskmelons. Relatively few of the pony crates or pony flats are used.

TABLE 11.—*Dimensions of western crates used in shipping cantaloups and other muskmelons*

| Type or variety of melon | Name of crate | Approximate inside dimensions [1] | Melons usually packed per crate |
|---|---|---|---|
| | | *Inches* | *Number* |
| Cantaloup and Honey Ball | Standard | 12×12×22⅛ | 45 or 36. |
| | Jumbo | 13×13×22⅛ | 45, 36, or 27. |
| | Pony | 11×11×22⅛ | 54 or 45. |
| | Standard flat | 4½×13½×22⅛ | 9, 11, 12, or 15. |
| | Jumbo flat | 5×14½×22⅛ | 6, 9, 12, or 15. |
| | Pony flat | 4×12×22⅛ | 9, 12, 15, or 18. |
| Honey Dew [2] | Standard | 6¾×16×22⅛ | 8, 9, 11, 12, or 15. |
| Casaba [2] | Jumbo | 7¾×16×22⅛ | 6, 8, or 9. |
| | Standard | 8¾×16×22⅛ | 5–8. |
| Persian | Pony | 6¾×12×22⅛ | 6–10. |
| | Standard | 7¾×14×22⅛ | 5–8. |
| | Jumbo | 9¾×16×22⅛ | 4–6. |
| | Special jumbo | 11¾×18×22⅛ | 3 or 4. |

[1] Outside length of slats is 23½ inches.
[2] The Honey Dew and casaba crates are sometimes used interchangeably.

In Colorado most of the cantaloup crop is shipped in standard or jumbo flat crates usually containing 9, 11, or 12 melons per crate.

Crates used in the eastern and central parts of the United States are generally known by the same names as those used in the West, yet there is considerable variation in construction and dimensions. The flat crates used in both the East and West have solid heads. The crates, other than flats in western districts, have slatted heads fabricated on triangular posts. In Michigan they have solid heads, while in Maryland, Delaware, and southeastern districts panel-end crates are used.

There are numerous variations in sizes of crates used in Maryland, Delaware, Michigan, and other Eastern and Midwestern States. In Maryland and Delaware the heads of the crates usually range as follows: 12, 13, 14, 15, or 16 inches square. The length of slats varies from 22 to 26 inches. In Michigan the dimensions of the heads of the crates commonly used are: 9, 10, 11, 12, 13, and 14 inches square, and the crates are of various lengths. The elimination of a large number of miscellaneous sizes used in eastern districts and standardization involving only a few popular sizes would facilitate quotations and improve marketing conditions. Melons packed in second-hand crates usually sell at a discount. More detail concerning sizes and construction of crates is contained in Farmers' Bulletin 1579.[3]

In the Eastern and Midwestern States the bushel basket, bushel hamper, and 12-quart climax basket are used in shipping considerable quantities of cantaloups.

## GRADES

Standards for grading cantaloups, Honey Dew melons, and Honey Ball melons have been issued by the Bureau of Agricultural Economics. These standards define the grade requirements and explain the terms used. Variety, firmness, maturity, form, and netting are factors considered in grading cantaloups. Defects, such as cracks, sunburn, decay, and damage by aphis, hail, disease, or other means, are considered as grade factors. Provision is made in the grading

[3] SPILMAN, H. A., and DAVIS, R. W. CONTAINERS USED IN SHIPPING FRUITS AND VEGETABLES. U.S. Dept. Agr. Farmers' Bull. 1579, 36 pp., illus. 1929.

standards for tolerances of stock which does not meet the grade requirements.

Requirements in the laws of some States are that shipments must meet certain minimum maturity tests, which specify the content of soluble solids in the juice of the edible portion of the melon. (For further details of the test for soluble solids, see p. 30.)

The size of melons is indicated by the size of the crate and the number of melons in the pack. The melons in a crate are supposed to be of nearly uniform size and tightly packed.

### GRADING AND PACKING

Whether the packing is done in a central or field packing shed in western districts, the stock is usually sorted or graded as to maturity and defects as the melons are transferred by hand from the field container to the packing bin.

The cantaloups suitable for shipping under ordinary refrigeration are usually kept separate from the "ripes" as they are transferred to the packing bin. These ripe melons may be sold locally or on nearby markets or precooled for shipment. Melons that are too green or too ripe for marketing or that are otherwise defective are placed in containers as they are sorted out. Careful picking in the field facilitates the work of the sorters.

The sizing is usually done by the packer who stands at the lower side of the packing bin with the packing bench before him. The packing bench usually slopes toward the packer. The crate is, therefore, in a slanting position while being packed and the melons remain where they are placed. The packer, observing the prevailing size of the cantaloups, selects the crate of most suitable size. He chooses cantaloups of uniform size and arranges them in the crate so as to obtain a tight pack.

It is important that the size be as nearly uniform as possible. Difference in size of melons in a crate makes it difficult to obtain a tight pack and detracts from the appearance and commercial value. Retailers discriminate against a crate containing melons that are not of uniform size, because they cannot be sold readily at one price per melon. The cantaloups should be placed in rows with their longest axis lengthwise in the crate. In western districts much of the packing is done by professional packers who move from one district to another as the season progresses.

When most of the cantaloups are at the right stage of maturity and have few defects, the sorter sometimes does some of the sizing, placing the various sizes at different positions in the bin or in different bins. The final responsibility for a good pack as to both size and grade rests with the packer.

In the eastern districts, where much of the packing is done on the farm, the cantaloups are usually poured from the field container to the sorting table which often has a slatted bottom. In some instances the sorting table consists of burlap stretched over a frame. The packer grades and sizes the melons as he packs.

Two principal methods of arrangement are in use when packing in the standard and jumbo crates. One is the 45 pack, in which there are 3 layers with 3 rows in each layer and 5 melons in each row. When the 45 pack is completed, every melon on each side should touch the slats, and the crate with the cover on should bulge slightly

on all sides. Cantaloups in a uniformly sized standard 45 pack will be approximately 4 inches in diameter and slightly less than 4½ inches in length. The second method of arrangement is the 36 pack, in which the melons are slightly larger than in a 45 pack in a crate of the same size, and in which there are 3 layers with 3 rows in each layer and 4 melons in each row. In alternate rows and alternate layers the melons are offset as contrasted with the 45-count arrangement (fig. 11). The pony 54 pack has the same arrangement as the standard 45 except that there are 6 instead of 5 melons in a row. Generally speaking, cantaloups are not sized as uniformly in most eastern districts as in western districts. Reports from some eastern districts and the Northwest indicate that standard crates are often packed with various numbers of cantaloups, usually ranging from 18 to 45.

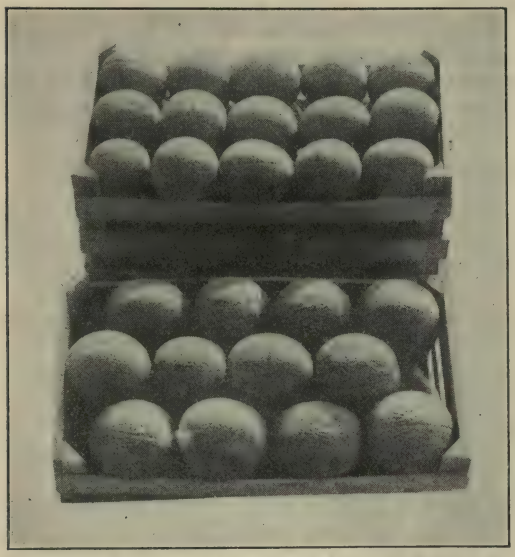

FIGURE 11.—Top view of a 45 pack and a 36 pack both in standard crates, showing different arrangement of melons in the crates. The lower pack is sometimes known as a special 36 pack.

In packing flat crates an arrangement similar to that of a single layer in the larger crates is generally used. But, cantaloups that are of a long type, such as Burrell Gem, are frequently arranged in a slightly diagonal position in the rows. Cantaloups should not be turned crosswise in the row, in packing, as is occasionally done in some of the eastern producing districts.

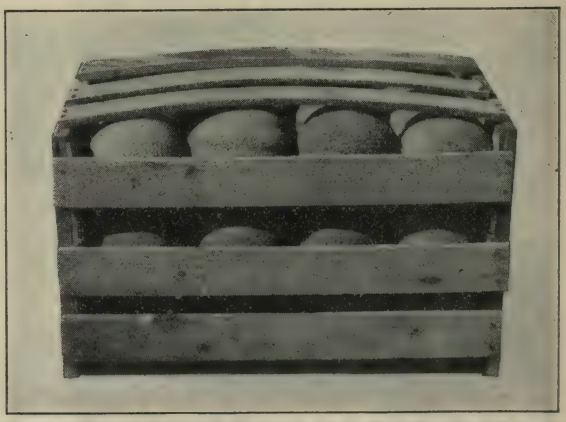

FIGURE 12.—An eastern type jumbo crate, 36 pack. In this pack, the melons in alternate layers are not offset. The pack has a satisfactory bulge.

It is important not only to have the cantaloups as nearly uniform in size as possible but also to have them fit snugly (fig. 12) so the crate will not be "slack packed" (fig. 13). Shipments arriving at market in a slack-packed condition with the cantaloups loose or jumbled in the crates usually sell at a considerable discount as compared with

well-packed shipments. It is also important not to have too much bulge on the pack as injury from bruising may result.

In the Imperial Valley and in Arizona most cantaloups are wrapped in tissue paper as they are packed. The wrappers frequently are pink and bear the brand or trade mark of the shipper. It is customary to pack about three melons on each side of the crate, unwrapped, as "show" melons to attract the eye of prospective buyers. In other districts, as central California, the cantaloups are mostly shipped unwrapped. In Colorado most varieties are shipped unwrapped, but the Burrell Gem, a pink-meat variety, is usually wrapped. In most eastern districts a relatively small proportion of the cantaloups are wrapped in preparing for market. Reports from Indiana indicate that less than one fourth are wrapped. Wrapping interferes somewhat with refrigeration, makes inspection more difficult, and may hide defective melons. Some shippers place small stickers, bearing their brands, on unwrapped melons.

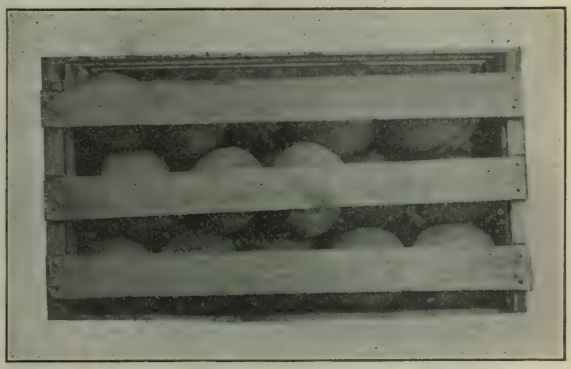

FIGURE 13.—A very aslck, poorly arranged pack of cantaloups in an eastern-type crate. One cantaloup in the upper layer has a piece of stem attached, indicating its green condition. A pack of this kind will sell in the markets at a large discount in price as compared with a tight, well-graded, well-arranged pack.

When the crate has been packed it is passed to a workman for lidding. Cement-coated nails are often used in making and lidding crates. Crates fastened with such nails show less loss from slats coming loose in transit or in handling.

In western districts, labels showing the shipper's brand are usually pasted on the crate, which is also marked with the size of crate and number of cantaloups in the pack as: "Standard 45", "Jumbo 36", etc. In eastern districts many crates are not labeled.

When the packing is done in field sheds or farm buildings, the packed crates are placed at once in trucks to be hauled to the refrigerator car when shipment is to be by rail. When packing is in a central shed and shipment is to be made by rail the packed crates are loaded on the cars as quickly as possible.

The method of operation in packing varies considerably. In some central packing houses sizing is done by machinery, and the crates are moved along by mechanical conveyors. The lidding may be done with the aid of a lidding press.

Both Honey Ball and Honey Dew melons are packed in temporary field sheds as well as in central sheds (fig. 14). They frequently show aphis residue and dust which detracts from their appearance and makes washing desirable. This is most conveniently done in a central packing house equipped with mechanical washers having soft rotating brushes which clean the melons. The defective melons are sorted out before washing.

If Honey Dew melons are washed, they are placed, after drying, in bins that are larger than the cantaloup packing bins. In packing the melons, excelsior is used to fill the spaces around the melons in the crate to prevent bruising; instead of excelsior some shippers have used colored strips of cellophane. Bruising is likely to result if there is much pressure on the melons from the slats and for this reason the diameter of the melons should be just sufficient to touch the top slat. In nailing on the lid slats, it is sometimes necessary to place cleats across the ends of the crates under the slats to prevent too much pressure on the melons. A slack pack of Honey Dew melons is likely to cause bruising.

Casaba and Persian melons are usually packed from wide bins and are handled in a manner somewhat similar to that used with Honey Dew (fig. 15).

FIGURE 14.—Packing Honey Dew melons in a western packing shed. Honey Ball melons are packed much like cantaloups, either wrapped or unwrapped. The standard and jumbo crates are largely used for Honey Ball melons. Stickers with brand names are often placed on Honey Ball and Honey Dew melons.

### LOADING

After the melons are packed the crates are segregated as to size and number of melons. They are then loaded in refrigerator cars if shipment is to be made by rail and if the packing has been done at a central shed. In some districts, particularly in Colorado, Honey Dew melons are mostly shipped under standard ventilation instead of under refrigeration, but the ripest melons are usually shipped under refrigeration.

In loading at central packing sheds, the crates are usually moved into the car on 2-wheeled trucks. The packed crates are sometimes stacked on light frames which permits the hand truck to be slipped under the entire stack.

Field-packed melons that are to be shipped by rail should be hauled to the car as soon as possible. Protection from dust and sun is conveniently provided by a tarpaulin. Many growers, however, fail to provide any protection for the melons from heat and dust. Some cantaloups are hauled to the loading station on wagons, but trucks are

better adapted to this purpose. Care should be exercised in hauling to prevent bruising the melons that are under the bulge in the crates.

In preparing the car for loading, the bunkers in each end of the car are filled with ice. The cars are equipped with floor racks to hold the bottom of the load several inches above the floor of the car and thus facilitate circulation of air. In loading the crates, spaces several inches wide, lengthwise of the car between the crates are allowed so that there will be a circulation of the cool air.

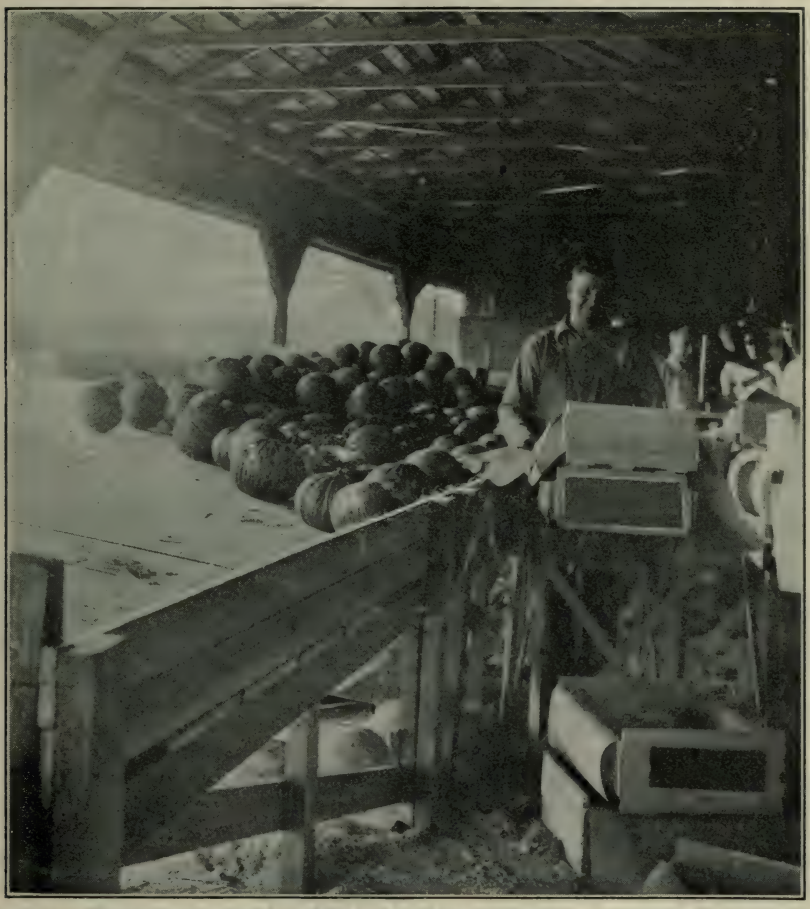

FIGURE 15.—Western packing house showing packing stand and packing bin containing casaba melons.

The large crates of cantaloups and Honey Ball melons in western districts usually are loaded on their sides three layers high in the car. The load of standard or pony crates usually is 7 rows wide whereas the load of jumbo crates is 6 rows wide. The load consists of eight stacks in each end of the car with a space a few feet wide extending across the car at the doorway. A full load of standard crates in the West usually contains 336 crates. In other districts there is considerable variation in the size of carloads. In South Carolina, for example, the usual load of standard crates is 4 layers high and 7 rows wide.

This load, when 16 stacks long, contains 448 crates. A load of about 400 standard crates is common in some districts.

Flat crates of cantaloups are usually loaded 6, 7, or 8 layers high and 6 rows wide. They are also sometimes loaded on edge 3 layers high and 15 or 16 rows wide. Loads frequently contain two or more sizes of crates.

As the standard, jumbo, or pony crates are loaded in the car, strips are usually nailed across the ends of the crates in each layer in each stack in the load. These car strips are about as long as the car is wide and are one half to 1 inch in thickness. Alternate strips in each layer should touch opposite sides of the car. They hold the load in place in transit and prevent injury to the melons in the lower layers from the weight of the load. In loading flat crates the strips are usually placed only on alternate layers (fig. 16).

FIGURE 16.—In loading this car of western flat crates of cantaloups, car strips were used between each two layers. The spaces between the rows facilitate circulation of cool air.

In the space at the doorway, which is usually about 2 feet wide, a bracing is constructed to hold the load in place in transit. This bracing usually consists of 2- by 4-inch uprights with 1- by 4-inch boards nailed across them. Two of these gates are used, one against each part of the load. One upright on each gate should touch the ceiling of the car to help hold the load in place. Short pieces of timber are placed between the two gates to hold them in position against the crates.

When cantaloups have been segregated as to maturity as they were packed, the crates containing the riper melons are often loaded next to the ice bunkers and in the lower layers. This part of the car has the lowest temperature.

Honey Dew crates are loaded flat. There is some variation in the arrangement of crates in the load. In one method of loading, the load is divided and center braced, with 8 stacks in each end of the car, 5 rows wide, and 6 layers high, containing 480 crates. In another arrangement there are 8 stacks in each end of the car, 5 rows wide with 2 stacks next to each bunker 7 layers high, and the remaining

12 stacks 6 layers high. This load contains 500 crates. Another arrangement is a divided load of 16 stacks, 7 layers, and 5 rows containing 560 crates.

For cantaloups, Honey Dew, and Honey Ball melons, the loads described are those used in a car with inside length of about 33 feet. Shorter cars of about 32 feet in length are usually loaded with only 15 stacks instead of 16 stacks.

When melons are trucked to market, the loads should be arranged securely and in a manner to prevent bruising of the melons. A tarpaulin can be used to advantage in protecting the load from sun, rain, or dust.

### PRECOOLING

During recent years the practice of precooling vine-ripened cantaloups and Honey Ball melons before shipping has met with considerable success in western districts. Under this method it has been possible to place melons of better edible qualities than formerly on the eastern markets. This is indicated by the premium in price generally received for the vine-ripened, precooled stock over the shipments handled under usual methods (p. 13).

In many of the precooled shipments the temperature of the melons is reduced to 45° or 50° F. after the car is loaded and before it is started to market. This is done by drawing air through the ice-filled bunkers into the car and forcing out the air as it is warmed through contact with the melons. The time required to precool the melons is one objection to this method of handling. Salt is sometimes added to the ice to hasten cooling. It may require from 6 to 24 hours to precool the load. The expense of precooling in some western districts has been reported as from $10 to $25 per car.

In some instances cantaloups have been precooled by placing the packed crates in a cold room provided for this purpose at central packing plants. Shipments of Honey Dew melons are seldom precooled.

### INSPECTION

Inspection of melons under Federal grades by the Federal-State inspection service at shipping points is optional with the shippers. Some States have laws, however, providing that shipments must meet certain requirements.

Under the Federal-State shipping-point inspection service, shippers in important districts can obtain inspection for a small charge per car. Under this service a certificate is furnished the shipper which shows the grade and type of pack of the melons and other pertinent information, such as the arrangement of the load and loader's count of the number of crates in the car. Federal inspection is also available in the large markets. During the calendar year 1932 more than 2,600 cars of cantaloups were inspected at shipping point under the Federal-State service.

In some States the hydrometer test for soluble solids in the juice of the edible portion is used as a basis in determining when the melons are sufficiently mature for shipment. There are some objections to the hydrometer test as an indicator of maturity because of the variations in the soluble solid content in the juice among mature melons of different varieties and under different field conditions. The sugar or soluble solid content of the earlier maturing cantaloups from the

crown set and of the first picking of the Honey Dew crop is higher than for later maturing melons from the same vines. This test is sometimes used as a check on the work of pickers in the field.

The legal minimum soluble solid content for Colorado shipments in 1933 was 8 percent for cantaloups and 10 percent for Honey Dew melons. Several years earlier the corresponding figures were 10 and 12 percent, respectively. The higher requirements were found to be impracticable during the latter part of the shipping seasons. In California the requirement for soluble solids in the juice of cantaloups has been 8 percent but this requirement has been changed to 9 percent effective in 1934.

The method of making the hydrometer test for soluble solids is briefly as follows: A sample is selected of a number of melons representing approximately the minimum stage of maturity in the lot to be inspected. They are cut open and the edible portion is removed with a spoon and put through a grinder. The juice is strained through a piece of cheesecloth into a vessel or cylinder. A hydrometer is then inserted in the juice and allowed to remain a few minutes until the air in the juice can escape. The percentage of soluble solids or sugar is shown by the hydrometer reading. A correction is made for the temperature of the juice.

Inspection at shipping point under standard grades tends to prevent unjustified rejection of the shipment at destination in sales made "f.o.b. usual terms." The official grades are a common language between shipper and distant buyer and as a basis for quoting prices are understood throughout the industry. The use of definite grading standards and inspection encourages better production methods among growers and more careful handling by those who are preparing the melons for shipment. Melons that are grown, graded, and packed in accordance with the best methods frequently bring a premium over melons that are poorly graded and packed.

## MARKETING METHODS

In most of the western producing districts marketing agencies, known either as shippers or distributors, largely control the sale of the crop. Some of these agencies have a permanent representative in the district with additional personnel during the shipping season. A common practice is for the marketing agencies to contract with growers. They usually advance money to the growers and furnish seed and packing material. For their services they have usually charged growers 15 percent of the "delivered at market" sale price of the shipments. Advances and costs of seeds and materials supplied are, of course, deducted from the sale price in settling with the growers.

Some of these marketing agencies are fruit and vegetable dealers in the large cities who consign shipments to their wholesale or jobbing houses or to wholesalers or jobbers in other cities. Some shipments are sold "delivered at destination", and some for cash loaded on cars at shipping point. The latter type of sale is known as a "cash-track" sale. Some sales are made on "wire order, shipping-point acceptance", in which the buyer, through telegraphic negotiations, accepts the carload f.o.b. shipping point at a specified price. A few sales are also made f.o.b. usual terms.

Independent growers in some districts sell a large part of their shipments "cash track". In Imperial Valley, Calif., in recent years, it has been estimated that about 30 percent of the rail shipments have been sold "cash track" to buyers who were in the district. The cash buyers in the producing districts are often representatives of wholesale or jobbing firms in the city markets. Some also operate independently as speculators or brokers.

In Delaware and on the Eastern Shore of Maryland, many of the cantaloups are sold at auction by the growers at the local shipping points. The farm-packed cantaloups are hauled by the growers to the auctions which are located at a number of rail shipping points. The buyers assemble and bid on the farmers' loads. Some auction sales are held in open sheds and some in the open. Local buyers, in some instances, manage the auction companies, charging the growers a small fee per package. A brokerage is also charged in some instances to city firms or others who buy through the local auctions.

After being sold at the local auctions the melons are loaded on trucks or cars and started to market. The buyers often consign their purchases to the large eastern markets. Some sales are made at shipping point and some delivered. The lack of uniformity in the pack and size of crates in eastern producing districts makes f.o.b. selling difficult.

In some eastern sections, local dealers buy field-packed cantaloups direct from the growers and load cars which are consigned or sold to city dealers. Local dealers, who in some instances are growers, often act as assembling and selling agents for other growers, charging a commission for their services. Local cooperative associations have been formed to market the crop in the Eastern Shore of Maryland and some other districts. Many growers sell their melons to trucker-peddlers for cash at the farm.

In Michigan, large quantities of cantaloups are sold at the Benton Harbor market. Dealers buy cantaloups from the growers as they are brought into the market, and ship mostly by motor truck to markets within a radius of several hundred miles. In 1932, the equivalent of about 550 cars of cantaloups were sold through the Benton Harbor market.

Disposal of cantaloups by growers and local dealers at roadside stands is of considerable importance, particularly in districts where there is a large population. A good trade can often be built up by these stand operators, if melons of good quality and condition are offered for sale, and especially if the display is attractive and if satisfactory parking facilities are provided.

In the large city markets, carloads of cantaloups or other muskmelons may be sold by the car-lot dealer in jobbing lots of approximately 10 to 50 crates to small jobbers or to large retailers. Motor-truck receipts are usually sold out in small lots by the dealer who receives them. Jobbers in the large cities and wholesalers in the smaller cities make sales direct to retailers in quantities of one crate or more. Chain stores handle some car-lot receipts in the larger markets. Car-lot brokers also aid in the distribution of melons in the city markets by acting as agents in placing available car-lot shipments in the hands of dealers or jobbers who need them.

In large markets, particularly in New York City, a considerable number of cars of cantaloups, Honey Ball, and Honey Dew melons

are sold at auction. In 1930 about 1,077 cars or 19 percent of the car-lot unloads of these melons in New York, were thus sold. In city auction sales of cantaloups and miscellaneous melons, the unit of sale is not the carload; the melons are sold to jobbers, retailers, or others in lots of various sizes, usually ranging from 20 to 40 crates.

Truck shipments of cantaloups from producing districts to markets are often delivered to a dealer to be sold. The dealer charges a commission for his services, usually 5 to 10 percent. The truckman sometimes hauls the melons to market for hire as the agent of the shipper; in other instances, the truckman buys the melons at shipping point and operates as a dealer or peddler. Some of these truck loads are sold direct to retailers or peddled to consumers.

## MARKET INFORMATION

Information from various sources is available to assist growers and shippers in marketing the crop of cantaloups and other muskmelons. Federal-State market news reports have been available during the shipping season each year in a number of the important producing districts. These daily reports have shown for the previous day, by States of origin, the number of car-lot shipments of the various classes of melons. Information on the market destination of shipments has also been included. In some districts where motor-truck shipments are important the market news reports have included records of these truck shipments obtained through the cooperation of certain State agencies.

The reports have contained statements of arrivals and supplies in the leading markets, prices in the markets, and prices in competing producing districts.

The reports of shipments and supplies in the markets are obtained by the Federal-State market news service through the cooperation of the railroads.

Federal and State agencies issue reports periodically through the season on the acreage and condition of the crop in various States. A weekly summary of car-lot shipments is issued by the Bureau of Agricultural Economics.

Trade papers, radio reports, and private reports received by shippers are also sources of supply and price information.

## MARKET OUTLETS

Western cantaloups and miscellaneous melons are distributed widely to markets in the United States and Canada. In 1931, shipments from the Imperial Valley, Calif., were made to every State, the District of Columbia, and Canada. About 340 cities received Imperial Valley shipments. A record of the destinations of 21,391 cars (more than 98 percent of the 1931 car-lot shipments) of Imperial Valley cantaloups and other muskmelons shows that about 30 percent went to markets in New York State, and that the four States of New York, Pennsylvania, Illinois, and Ohio received about 60 percent (table 12 and fig. 17).

The distribution of the Imperial Valley crop in 1931 was probably more nearly normal than in 1932 when shipments were 38 percent less than in 1931. In 1932 shipments were made to only 240 markets.

TABLE 12.—*Distribution by States of destination of melon shipments from leading producing districts, reported during period of operation of market news stations, 1931*

| State of destination | Car-lot shipments | | | | Motor-truck shipments of cantaloups from Delaware and Eastern Shore of Maryland |
|---|---|---|---|---|---|
| | Cantaloups and other muskmelons from Imperial Valley, Calif. | Cantaloups from Arizona | Cantaloups from Colorado | Cantaloups from Delaware and Eastern Shore of Maryland | |
| | *Cars* | *Cars* | *Cars* | *Cars* | *Car-lot quantities* |
| Alabama | 56 | 7 | | | |
| Arizona | 13 | 1 | | | |
| Arkansas | 25 | | | | |
| California | 861 | 1 | | | |
| Colorado | 182 | 289 | 3 | | |
| Connecticut | 206 | 48 | 4 | 17 | 22 |
| Delaware | 1 | | | | 10 |
| District of Columbia | 210 | 19 | 4 | | [1] 4 |
| Florida | 116 | 6 | 9 | 1 | |
| Georgia | 61 | 2 | 1 | | |
| Idaho | 19 | | | | |
| Illinois | 2,007 | 701 | 286 | | |
| Indiana | 201 | 54 | | | |
| Iowa | 179 | 59 | 1 | | |
| Kansas | 85 | 37 | 2 | | |
| Kentucky | 91 | 29 | | | |
| Louisiana | 177 | 18 | 3 | | |
| Maine | 35 | 10 | 3 | 9 | |
| Maryland | 479 | 55 | 6 | 1 | [1] 1 |
| Massachusetts | 985 | 99 | 62 | 109 | 2 |
| Michigan | 804 | 142 | 5 | 14 | |
| Minnesota | 323 | 71 | | | |
| Mississippi | 6 | | | | |
| Missouri | 991 | 292 | 128 | | |
| Montana | 64 | 3 | | | |
| Nebraska | 168 | 39 | 7 | | |
| Nevada | 17 | | | | |
| New Hampshire | 4 | | | 4 | |
| New Jersey | 178 | 40 | 8 | 11 | 94 |
| New Mexico | 16 | 5 | 3 | | |
| New York | 6,422 | 596 | 253 | 126 | 909 |
| North Carolina | 41 | 2 | | | |
| North Dakota | 23 | | | | |
| Ohio | 1,273 | 262 | 89 | 14 | |
| Oklahoma | 79 | 16 | | | |
| Oregon | 194 | | | | |
| Pennsylvania | 2,913 | 520 | 208 | 64 | 387 |
| Rhode Island | 105 | 18 | 8 | 20 | 1 |
| South Carolina | 12 | | | | |
| South Dakota | 19 | 4 | | | |
| Tennessee | 154 | 33 | 1 | | |
| Texas | 257 | 71 | 3 | | |
| Utah | 84 | 1 | | | |
| Vermont | 18 | 6 | 1 | 2 | |
| Virginia | 104 | 7 | 1 | | |
| Washington | 220 | | | | |
| West Virginia | 95 | 30 | 3 | 1 | |
| Wisconsin | 258 | 52 | | | |
| Wyoming | 20 | 2 | 1 | | |
| Canada | 540 | 125 | | 1 | |
| Total [2] | 21,391 | 3,772 | 1,103 | 394 | 1,430 |

[1] Incomplete.
[2] On which destinations were reported.

A record of destinations of about 85 percent of the car-lot shipments of cantaloups from Arizona in 1931 shows shipments to 38 States, the District of Columbia, and Canada (table 12 and fig. 18). About 19 percent of these car-lot shipments of Arizona cantaloups went to Illinois, which was the principal State of destination. Three States—Illinois, New York, and Pennsylvania—received about 48 percent of

the Arizona shipments according to the billings. In 1931, 188 cities were reported as destinations of Arizona shipments. In 1932, Arizona shipments of cantaloups totaled 3,020 cars and were 32 percent less

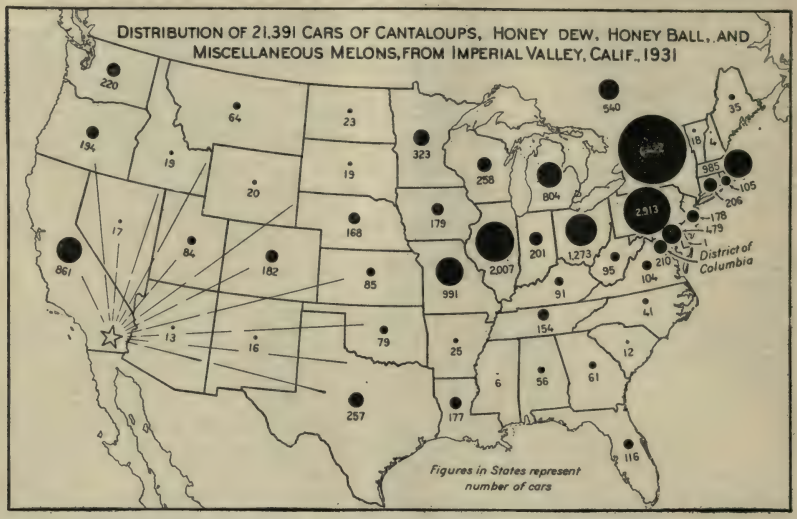


FIGURE 17.—Shipments of cantaloups and other muskmelons from the Imperial Valley, Calif., went to every State in 1931.

than the 1931 shipments and much smaller than in any year since 1926. The 1932 Arizona crop was distributed to about 140 cities in 36 States, the District of Columbia, and Canada.

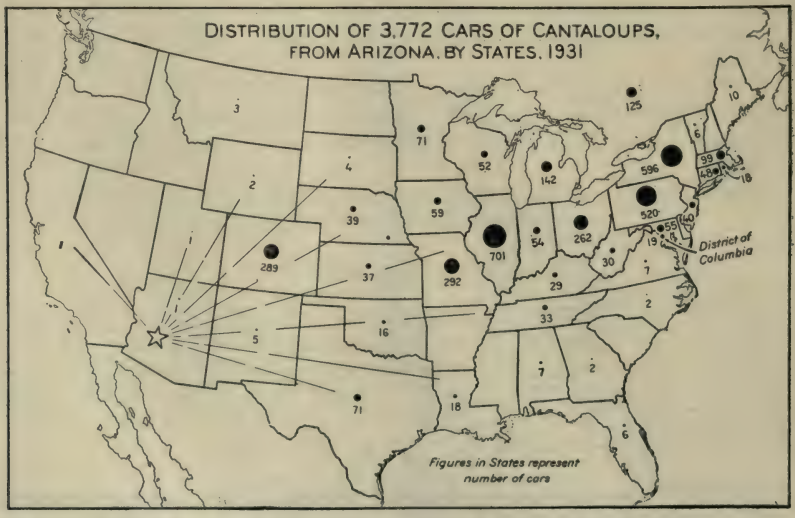


FIGURE 18.—Arizona cantaloups are marketed in a large number of States.

Colorado cantaloups in 1931, according to a record of distribution of 1,103 cars or about 60 percent of the shipments, went to 26 States and the District of Columbia (table 12 and fig. 19). The leading State used as a market outlet was Illinois, to which about 26 percent

of the cars were shipped. The next three States in importance as market outlets for Colorado shipments were New York, Pennsylvania, and Missouri. These three States included destinations of about 53 percent of the recorded shipments from Colorado.

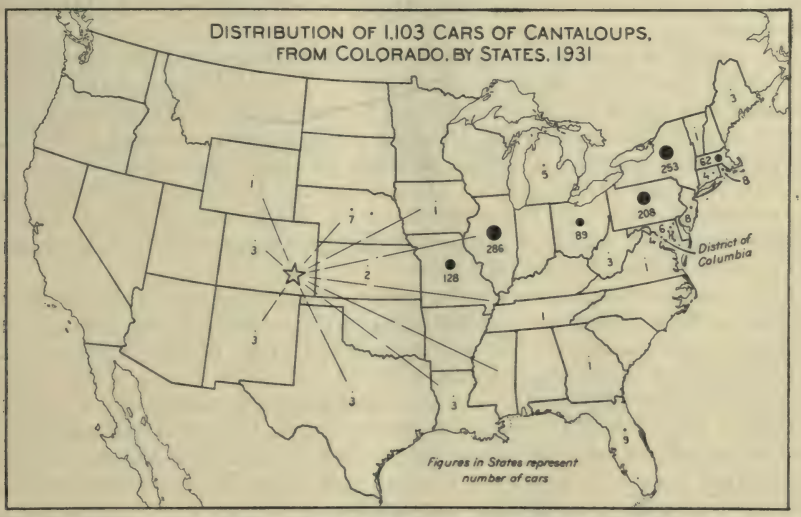


FIGURE 19.—Three States—Illinois, New York, and Pennsylvania—received more than two thirds of the shipments of Colorado cantaloups for which destinations were recorded in 1931.

The distribution of eastern cantaloups is not Nation-wide. A larger proportion of the eastern crop moves by motor-truck than is the case with the western crop.

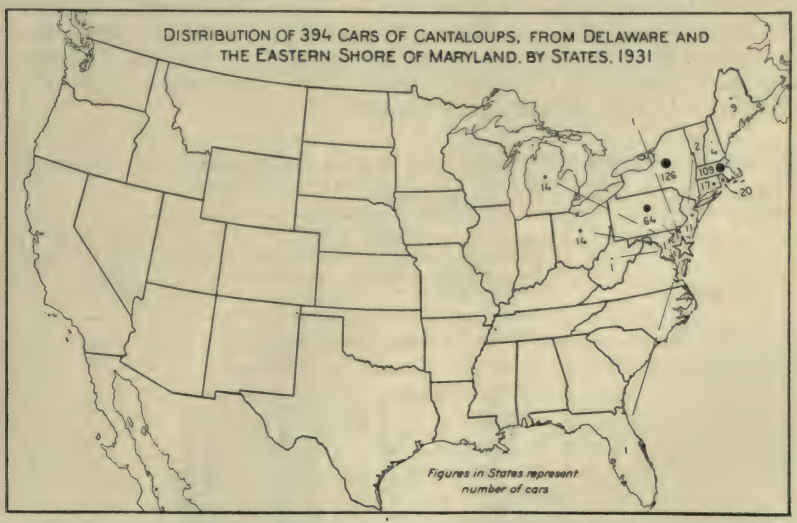
DISTRIBUTION OF 394 CARS OF CANTALOUPS, FROM DELAWARE AND THE EASTERN SHORE OF MARYLAND, BY STATES, 1931
126
64
Figures in States represent number of cars

FIGURE 20.—Car-lot shipments of cantaloups from Delaware and the Eastern Shore of Maryland go largely to the Middle Atlantic and New England States.

The record of destinations of shipments of 394 cars from Delaware and the Eastern Shore of Maryland representing about two thirds of the 1931 car-lot shipments from these States shows distribution to

14 States and Canada (table 12 and fig. 20). New York and Massachusetts together received about 60 percent of the car lots for which destinations were reported. A few car-lot shipments from Delaware and the Eastern Shore of Maryland went as far west as Detroit, but most of the rail movement was to points in the region from Pittsburgh eastward.

The greater part of the movement from Delaware and the Eastern Shore of Maryland is by motor-truck. The 1931 records of destinations of the equivalent of 1,430 cars moved by truck from this district show that 8 States and the District of Columbia received these shipments. These records are somewhat incomplete, particularly as to Baltimore and Washington. Trucks going by ferry to these points were not included in the record. New York and Pennsylvania together received about 90 percent of the recorded truck movement from this district (table 12).

The market outlets for a large part of the cantaloups from Michigan, Indiana, New Jersey, and other States in the North Central and North Atlantic regions are within a few hundred miles of the producing districts. Most of the movement is by truck.

Markets for the crop from the Carolinas are chiefly in the North Atlantic region. The principal markets for Arkansas cantaloups are in the Middle West, but some shipments come to the Middle Atlantic and New England States. Cantaloups from Washington are marketed chiefly in cities in the Northwest.

Freight and refrigeration charges are important items in the cost of marketing melons and they influence the final distribution of the crop. Changes are frequently made in transportation rates, but as a general indication of these costs a tabulation of freight and refrigeration charges in effect in May 1933 from leading producing districts to New York and Chicago is given in table 13. The freight and refrigeration from Brawley, Calif., to New York was about $1.52 per standard crate, and to Chicago about $1.28, according to this tabulation. From Laurinburg, N.C., the charge to New York was about 62 cents as compared with 78 cents to Chicago.

TABLE 13.—*Freight and refrigeration charges on cantaloups from representative shipping points to New York and Chicago* [1]

| Shipping point | Freight rate per 100 pounds on carloads of specified minimum weights to— | | Standard refrigeration per car to— | | Approximate freight and refrigeration charges per standard crate to— | |
|---|---|---|---|---|---|---|
| | New York | Chicago | New York | Chicago | New York | Chicago |
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| Brawley, Calif. | 1.75 | 1.46 | 110.00 | 95.00 | 1.52 | 1.28 |
| Turlock, Calif. | 1.75 | 1.46 | 110.00 | 95.00 | 1.52 | 1.28 |
| Phoenix, Ariz. | 1.75 | 1.46 | 105.00 | 95.00 | 1.50 | 1.28 |
| Rocky Ford, Colo. | 1.24 | .70 | 85.00 | 70.00 | [2] 2.47 | [2] 2.29 |
| Mesquite, N.Mex. | 1.28 | 1.04 | 95.00 | 80.00 | 1.15 | .95 |
| Horatio, Ark. | .93 | .66 | 85.00 | 70.00 | .84 | .62 |
| Salisbury, Md. | .38 | .66 | 55.00 | 82.50 | .40 | .66 |
| Laurinburg, N.C. | .665 | .82 | 65.50 | 90.00 | .62 | .78 |
| Blackville, S.C. | .72 | .86 | 69.00 | 90.00 | .66 | .81 |

[1] These rates, as of May 1933, are based on usual number of crates loaded per car, assuming a billing weight of 68 pounds for a standard crate, and 28 pounds for a standard flat crate. The minimum load in California, Arizona, Colorado, and New Mexico is 20,000 pounds, and in the other States listed, 24,000 pounds. This tabulation is presented merely to show approximate transportation charges and can have no standing in adjusting claims with the carriers.

[2] Charges per standard flat crate.

An analysis of the records of cantaloup receipts in 12 important markets, well scattered geographically from Boston to San Francisco, shows that in 1932 about 33 percent of the reported receipts were California rail shipments (table 14). The reported truck receipts, which were incomplete, amounted to about 39 percent of the total reported supply for the 12 cities. Rail receipts from districts other than the West amounted to only about 8 percent. There was a wide difference in the source of supply among the 12 markets. Los Angeles received 94 percent of its supply by truck, whereas little more than 1 percent of the Boston supply came by truck. About half of the total supply in these 12 markets came as rail receipts from the Western States.

TABLE 14.—*Source of shipments, method of transportation, and volume of cantaloup supply in 12 markets in 1932*

| Market | Rail and boat unloads from— | | | | | Truck receipts [2] | Total supply |
|---|---|---|---|---|---|---|---|
| | California | Arizona | Colorado | Other Western States [1] | Eastern, Southern or Midwestern States | | |
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Car-lot quantities* | *Car lots* |
| Atlanta, Ga. | 14 | 0 | 0 | 1 | [3] 10 | 119 | 144 |
| Boston, Mass. | 638 | 172 | 221 | 78 | 283 | 2 | 1,394 |
| Chicago, Ill. | 935 | 336 | 229 | [4] 132 | 194 | [5] | 1,826 |
| Denver, Colo. | 99 | 49 | 1 | 20 | 0 | 173 | 342 |
| Kansas City, Mo. | 123 | 34 | 50 | 2 | 65 | 27 | 301 |
| Los Angeles, Calif. | [3] 122 | 0 | 0 | 0 | 0 | 1,979 | 2,101 |
| New York, N.Y. | 1,791 | 443 | 325 | [4] 170 | [3] 332 | 1,305 | 4,366 |
| Philadelphia, Pa. | 527 | 206 | 53 | 27 | [3] 127 | 1,644 | 2,584 |
| Pittsburgh, Pa. | 406 | 121 | 207 | 35 | 154 | [5] | 923 |
| St. Louis, Mo. | 241 | 42 | 55 | 14 | 102 | 250 | 704 |
| Salt Lake City, Utah | 34 | 0 | 0 | 28 | 0 | 182 | 244 |
| San Francisco, Calif. | [3] 261 | 4 | 0 | 0 | 0 | 420 | 685 |
| Total | 5,191 | 1,407 | 1,141 | 507 | 1,267 | 6,101 | 15,614 |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Proportion of total | 33 | 9 | 8 | 3 | 8 | 39 | 100 |

[1] As here used includes New Mexico and other States west of Colorado and New Mexico, excepting California and Arizona.
[2] Truck receipts are mostly from producing districts within a few hundred miles of the market. The quantities are somewhat incomplete for most cities as reports of shipments direct to retailers and consumers and some shipments to wholesalers are not available.
[3] Includes less-than-carload lots as follows: Atlanta, 2; Los Angeles, 8; Philadelphia, 16; New York, 1; San Francisco, 5.
[4] Includes 1 car from Mexico at Chicago, and 3 cars from Mexico in New York.
[5] Reports of truck receipts not available.

Car-lot unloads of cantaloups and other muskmelons in 66 cities for which records are available totaled 23,677 cars in 1932 compared with 31,217 cars in 1931, and 31,031 cars in 1930. These figures represent 90, 85, and 86 percent, respectively, of the total United States car-lot shipments of these melons. The sources of the car-lot supply for each of the 66 cities for 1932 are shown in table 15. In 1932 the United States car-lot shipments were more than one fourth less than in 1931 and the 66 cities received a larger proportion of the shipments.

The population of the metropolitan districts of these 66 cities in 1930 totaled between 70 and 75 percent of the population in places of 2,500 or more in the United States and about 40 percent of the total United States population.

TABLE 15.—*Car-lot and boat unloads of cantaloups and other muskmelons in 66 markets, 1932*

| Market | Shipments from indicated State of origin | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Arizona | Arkansas | California | Colorado | Delaware | Florida | Georgia | Illinois | Indiana | Iowa | Louisiana | Maryland | Michigan | Nevada | New Mexico | North Carolina | South Carolina | Texas | Utah | Washington | Other domestic [1] | Foreign [2] | Total |
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| Akron, Ohio | 11 | 2 | 17 | 4 | 1 | | | | 5 | | | | | | 1 | | | 1 | | | | | 42 |
| Albany, N.Y | 26 | 3 | 137 | 15 | 3 | | | | | | | 3 | | | 12 | | | 14 | | | | | 213 |
| Atlanta, Ga | | | 40 | 2 | | | 2 | | | | | 5 | | | 1 | | | 2 | | | | | 52 |
| Baltimore, Md | 44 | 4 | 296 | 39 | | 2 | 5 | | | | | 9 | | | | 7 | 18 | | | | 10 | 4 | 438 |
| Birmingham, Ala | | | 19 | 2 | | | 2 | | | | | | | | 1 | | | 1 | | | | | 25 |
| Boston, Mass | 175 | 14 | 1,020 | 267 | 54 | | 1 | 1 | | | | 109 | | 3 | 63 | 19 | 27 | 53 | 8 | 1 | 8 | 5 | 1,828 |
| Bridgeport, Conn | 19 | | 54 | 10 | | | | | | | | | | | 3 | | | | | | | | 86 |
| Buffalo, N.Y | 44 | 12 | 222 | 47 | 16 | | | | 2 | | | 20 | | | 24 | | 7 | 7 | | | 2 | | 403 |
| Chicago, Ill | 345 | 52 | 1,256 | 290 | 1 | | | 26 | 57 | 2 | 3 | | | 15 | 104 | | | 53 | 12 | | | 1 | 2,217 |
| Cincinnati, Ohio | 65 | 20 | 268 | 110 | 2 | | 3 | | 28 | 2 | | | | | 9 | | | 1 | | | | | 508 |
| Cleveland, Ohio | 133 | 18 | 422 | 113 | 20 | | 3 | | 47 | 3 | 1 | 14 | | | 34 | 2 | | 28 | | | | 1 | 839 |
| Columbus, Ohio | 18 | 10 | 86 | 9 | 1 | | | | 9 | | | 3 | | | 5 | | | 6 | | | | | 147 |
| Dallas, Tex | | | 16 | | | | | | | | | | | | 1 | | | 9 | | | | | 26 |
| Dayton, Ohio | 3 | 1 | 21 | 6 | | | | | 2 | | | | | | 2 | | | | | | | | 35 |
| Denver, Colo | 49 | | 106 | 1 | | | | | | | | | | | 20 | | | | | | | | 176 |
| Des Moines, Iowa | 11 | 7 | 33 | | | | | | | | | | | | 1 | | | 1 | | | | | 53 |
| Detroit, Mich | 132 | 31 | 482 | 40 | 3 | | 6 | | 32 | | | 12 | | | 35 | | | 14 | | | | 3 | 790 |
| Duluth, Minn | 15 | | 16 | | | | | | | | | | | | | | | 5 | | | | | 36 |
| El Paso, Tex | | | 16 | | | | | | | | | | | | | | | | | | | | 16 |
| Evansville, Ind | 3 | 1 | 7 | | | | | | | | | | | | | | | | | | | | 11 |
| Fort Worth, Tex | | | 10 | | | | | | | | | | | | | | | 7 | | | | | 17 |
| Grand Rapids, Mich | 11 | 3 | 48 | | | | | | 6 | | | | | | | | | | | | | | 68 |
| Hartford, Conn | 26 | 2 | 139 | 17 | 2 | | | | | | | 3 | | | 2 | | | | | | | | 191 |
| Houston, Tex | | | 12 | 1 | | | | | | | | | | | 2 | | | 1 | | | | | 16 |
| Indianapolis, Ind | 25 | 3 | 76 | 15 | | | | | 4 | | | | | | 1 | | | 1 | | | | | 125 |
| Jacksonville, Fla | | | 18 | 3 | 3 | | | | | | | 1 | | | 2 | | | 1 | | | | | 28 |
| Kansas City, Mo | 36 | 51 | 153 | 58 | | | | | | 1 | 3 | | | | 2 | | | 8 | | | 4 | 1 | 317 |
| Lexington, Ky | 2 | | 12 | 4 | | | 1 | | 3 | | | | | | 1 | | | | | | | | 23 |
| Los Angeles, Calif | | | 160 | | | | | | | | | | | | | | | | | | | | 160 |
| Louisville, Ky | 15 | | 44 | 11 | | | | | | | | | | | 1 | | | | | | | | 71 |
| Memphis, Tenn | 2 | 1 | 41 | | | | | | | | | | | | 2 | | | 3 | | | | | 49 |
| Milwaukee, Wis | 54 | 7 | 116 | 5 | | | | | 3 | | 1 | | 13 | | 8 | | | 7 | | | | | 214 |
| Minneapolis, Minn | 53 | 8 | 157 | 4 | | | | | | 3 | | | | | | | | 12 | 2 | | | | 239 |
| Nashville, Tenn | 3 | 2 | 17 | 2 | | 1 | 1 | | | | | | | | 1 | | | | | | | | 27 |
| Newark, N.J | 64 | | 230 | 61 | | | 2 | | | | | | | | | 5 | | 1 | | | | | 363 |
| New Haven, Conn | 31 | 3 | 48 | 6 | 1 | | | | | | | | | | 3 | | | 3 | | | | | 95 |
| New Orleans, La | 11 | 1 | 115 | 18 | | | | | | | 3 | | | | 6 | | 1 | 35 | | | | | 190 |
| New York, N.Y | 486 | 44 | 5,401 | 583 | 1 | 3 | 19 | | 2 | | 3 | 18 | | | 63 | 75 | 94 | 74 | 103 | | 5 | 457 | 7,431 |
| Norfolk, Va | | | 20 | 1 | | | 1 | | | | | | | | | 1 | 1 | | | | | | 24 |

| | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oklahoma City, Okla. | | | 14 | | | | | | | | | | | | | | | | | | | | 14 |
| Omaha, Nebr. | 20 | 6 | 81 | 5 | | | | | | | | | | | 1 | | | 1 | | 1 | 2 | | 117 |
| Peoria, Ill. | 12 | 1 | 9 | | | | | | 1 | | | | | | | | | | | | | | 23 |
| Philadelphia, Pa. | 211 | 5 | 1,261 | 175 | | 3 | 11 | | 1 | | | | | | 7 | 43 | 43 | 7 | 20 | | | 15 | 1,802 |
| Pittsburgh, Pa. | 122 | 12 | 603 | 275 | 33 | 3 | 3 | | 8 | | | 19 | | | 35 | 2 | 3 | 69 | | | 2 | 3 | 1,192 |
| Portland, Maine | 16 | | 46 | 8 | 7 | | | | | | | 1 | | | 8 | | | 1 | | | | | 87 |
| Portland, Oreg. | | | 160 | | | | | | | | | | | | | | | | | 27 | 1 | | 188 |
| Providence, R.I. | 36 | 2 | 82 | 26 | 11 | | | | | | | 18 | | | 12 | 5 | 6 | 1 | 4 | | | | 203 |
| Richmond, Va. | 1 | | 12 | 1 | | | 1 | | | | | | | | 1 | 1 | 13 | | | | | | 30 |
| Rochester, N.Y. | 25 | 9 | 86 | 10 | 6 | | 1 | | 1 | | | 9 | | | 8 | | | 14 | | | | | 169 |
| St. Louis, Mo. | 43 | 61 | 329 | 85 | | | | | | 13 | 7 | | | | 8 | | | 21 | 6 | | | | 573 |
| St. Paul, Minn. | 23 | 4 | 48 | 1 | | | | | 1 | 1 | | | | | 1 | | | 2 | | | | | 81 |
| Salt Lake City, Utah | | | 36 | | | | | | | | | | | 28 | | | | | | | | | 64 |
| San Antonio, Tex. | | | 1 | 1 | | | | | | | | | | | 1 | | | 1 | | | | | 4 |
| San Francisco, Calif. | 4 | | 379 | | | | | | | | | | | | | | | | | | | | 383 |
| Seattle, Wash. | 1 | | 188 | | | | | | | | | | | | | | | | | 17 | 2 | | 208 |
| Shreveport, La. | | | 2 | | | | | | | | | | | | | | | | | | | | 2 |
| Sioux City, Iowa | 14 | | 21 | | | | | | | | | | | | 3 | | | 1 | | | | | 39 |
| Spokane, Wash. | | | 33 | | | | | | | | | | | | | | | | | 22 | | | 55 |
| Springfield, Mass. | 16 | 2 | 78 | 3 | 1 | | | | | | | 2 | | | 3 | | | 2 | | | | | 107 |
| Syracuse, N.Y. | 26 | 6 | 72 | 11 | 6 | | | | | | | 2 | | | 8 | | | 6 | | | | | 137 |
| Tampa, Fla. | 2 | | 35 | 9 | | | | | | | | | | | 1 | | | 3 | | | 1 | | 51 |
| Terre Haute, Ind. | | | | | | | | | | | | | | | | | | | | | | | 0 |
| Toledo, Ohio | 14 | | 35 | 2 | | | | | 4 | | | | | | 2 | | | 3 | | | | | 60 |
| Washington, D.C. | 38 | | 307 | 29 | | | 3 | | | | | 2 | | | | | 1 | 4 | | | 3 | 1 | 388 |
| Worcester, Mass. | 4 | | 2 | | | | | | | | | | | | | 1 | | | | | | | 7 |
| Youngstown, Ohio | 15 | 2 | 61 | 16 | | | | | | | | | | | 6 | | 1 | 3 | | | | | 104 |
| Total | 2,555 | 410 | 15,332 | 2,401 | 172 | 12 | 65 | 27 | 216 | 25 | 21 | 250 | 13 | 46 | 515 | 161 | 215 | 487 | 155 | 68 | 40 | 491 | 23,677 |

[1] Includes unloads from various States as follows: Kansas, 8; Missouri, 2; New Jersey, 4; Oregon, 8; Virginia, 13; unknown, 5.

[2] Total foreign unloads in terms of carloads were: Brazil, 1; Chile, 455; Mexico, 10; Portugal, 1; Spain, 24. New York City foreign unloads were: Chile, 427; Mexico, 9; Portugal, 1; Spain, 20.

New York City is by far the most important market for cantaloups and other muskmelons. In 1932, 6,974 cars of domestic melons or 27 percent of the United States car-lot shipments were unloaded in New York City. There were also 457 car lots received from foreign sources, mostly Chile.

A careful study of table 15 not only shows the source of car-lot supply of each of the 66 cities, but also, in a general way, the region into which the crop from each State is distributed. For example, the table shows that 61 percent of the reported Indiana unloads were in three cities: Chicago, Cincinnati, and Cleveland. A large part of the Indiana crop goes to markets in Illinois, Ohio, Indiana, and Michigan. Similarly 57 percent of the Arkansas unloads in the 66 cities were in 6 cities: Kansas City (Mo.), St. Louis, Chicago, Cleveland, Cincinnati, and Detroit. Markets in the region which includes these cities are the principal outlet for the Arkansas crop. However, there are considerable receipts of Arkansas cantaloups in the eastern markets. In 1932, New York City received 11 percent and Boston over 3 percent of the total Arkansas unloads in 66 markets. A large part of the Carolina shipments go to New York City and Philadelphia. In 1932 these 2 markets received 73 percent and 64 percent of the North Carolina and South Carolina unloads respectively in the 66 markets (table 15).

A study of the market distribution of cantaloups and other muskmelons shows that a larger proportion of the car-lot shipments go to the large cities than is the case for any of 15 other important fruits and vegetables. In 1930, 62 percent and in 1931, 60 percent of the car-lot shipments of cantaloups and other muskmelons went to 10 cities with metropolitan populations of more than 1,000,000. For watermelons, only 30 percent of the shipments in 1930 and 32 percent in 1931 went to these 10 large cities. For the other 14 fruits and vegetables studied, the corresponding percentages generally varied between 30 and 60 percent. The highly perishable nature of cantaloups is one explanation of the fact that they are not distributed in carloads to as small cities as are some of the other commodities. Large quantities of cantaloups and other muskmelons are distributed by truck from the large car-lot markets to smaller cities and towns in the surrounding trade territory.

Separate records of car-lot unloads of cantaloups, Honey Ball, casaba, Honey Dew, Persian melons, and mixed melons are available for a number of the larger markets. These unloads for 1932 in 23 markets are shown in table 16. New York City is the best market for miscellaneous melons, not only as to quantity used but also as to the proportion of the total supply of cantaloups and miscellaneous melons. Out of a total of 7,431 cars unloaded at New York in 1932, 3,790 or 51 percent were Honey Ball, Honey Dew, casaba, and Persian melons. Philadelphia, also, is a good market for the miscellaneous group of melons. In Chicago, cantaloups made up about 82 percent of the car-lot unloads of cantaloups and other muskmelons.

TABLE 16.—*Car-lot unloads of cantaloups, Honey Ball, casaba, Honey Dew, Persian, and mixed melons in certain markets, 1932*

| Market | Cantaloups | Honey Ball melons | Casaba melons | Honey Dew melons | Persian melons | Mixed melons and other muskmelons[1] | Total |
|---|---|---|---|---|---|---|---|
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| Atlanta, Ga | 23 | 1 | 0 | 15 | 0 | 13 | 52 |
| Baltimore, Md | 248 | 34 | 0 | 89 | 0 | 67 | 438 |
| Boston, Mass | 1,392 | 41 | 39 | 294 | 1 | 61 | 1,828 |
| Chicago, Ill | 1,826 | 55 | 3 | 266 | 13 | 54 | 2,217 |
| Cincinnati, Ohio | 451 | 24 | 0 | 23 | 1 | 9 | 508 |
| Cleveland, Ohio | 674 | 41 | 0 | 101 | 4 | 19 | 839 |
| Dallas, Tex | 24 | 0 | 0 | 2 | 0 | 0 | 26 |
| Denver, Colo | 169 | 0 | 0 | 6 | 1 | 0 | 176 |
| Detroit, Mich | 659 | 16 | 0 | 86 | 2 | 27 | 790 |
| Fort Worth, Tex | 17 | 0 | 0 | 0 | 0 | 0 | 17 |
| Kansas City, Mo | 274 | 3 | 0 | 39 | 0 | 1 | 317 |
| Minneapolis, Minn | 215 | 5 | 0 | 12 | 0 | 7 | 239 |
| New Orleans, La | 156 | 17 | 0 | 11 | 0 | 6 | 190 |
| New York, N.Y | 3,060 | 1,031 | 34 | 2,661 | 64 | 581 | 7,431 |
| Omaha, Nebr | 106 | 0 | 0 | 9 | 0 | 2 | 117 |
| Philadelphia, Pa | 924 | 224 | 1 | 523 | 5 | 125 | 1,802 |
| Pittsburgh, Pa | 923 | 56 | 0 | 136 | 7 | 70 | 1,192 |
| Portland, Oreg | 177 | 0 | 0 | 1 | 0 | 10 | 188 |
| St. Louis, Mo | 454 | 26 | 0 | 80 | 0 | 13 | 573 |
| St. Paul, Minn | 72 | 3 | 0 | 5 | 0 | 1 | 81 |
| Salt Lake City, Utah | 62 | 0 | 0 | 1 | 0 | 1 | 64 |
| Seattle, Wash | 180 | 0 | 2 | 8 | 0 | 18 | 208 |
| Washington, D.C | 220 | 37 | 1 | 117 | 8 | 5 | 388 |
| Total | 12,306 | 1,614 | 80 | 4,485 | 106 | 1,090 | 19,681 |

[1] Includes cars containing 2 or more of the specified varieties or types and a few cars of miscellaneous varieties or types not listed.

## PRICES

The prices of cantaloups and other melons are influenced by a number of factors among which are changes in the general price level, changes in volume of production from year to year in any shipping district and in competing districts, variations in time of harvesting as it affects volume of daily shipments and competition on the markets among shipping districts, average quality of the crop and legislative restrictions as to quality and condition of shipments, weather conditions, and competition from other fruits and melons.

From 1929 to 1932 melon prices trended downward in general accord with the downward movement of the general price level (table 17). For the country as a whole, there was not a wide fluctuation in the production of cantaloups and other muskmelons during this period, but rail shipments of cantaloups were somewhat lower in 1930 and 1931 than in 1928 and 1929, and the 1932 cantaloup rail shipments were about 40 percent less than the average shipments of 1928 and 1929, partly because large quantities were not marketed from some districts. The car-lot shipments of miscellaneous melons in 1930 and 1931 were greater than in 1928 and 1929, but there was a sharp decrease in shipments in 1932.

The reasons for price fluctuations are complex and no attempt is here made to explain the year-to-year changes for any State or district or the differences in price among the various States and districts.

TABLE 17.—*Average seasonal price paid to growers per crate for cantaloups and miscellaneous melons,* [1] *1928–32*

| Group and State or district | 1928 | 1929 | 1930 | 1931 | 1932 |
|---|---|---|---|---|---|
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| Early shipping group: | | | | | |
| California, Imperial Valley | 1.60 | 1.63 | 1.32 | 1.14 | 1.15 |
| Florida | 2.00 | 2.00 | 1.75 | 1.50 | 1.00 |
| Texas, early district | 1.20 | 2.00 | 2.25 | .81 | 2.00 |
| Average | 1.60 | 1.64 | 1.34 | 1.14 | 1.15 |
| Second-early shipping group: | | | | | |
| Arizona | 1.34 | 1.25 | .90 | .85 | .40 |
| Arkansas | 1.02 | 1.22 | .90 | .88 | .45 |
| California, other than Imperial Valley | 1.06 | .95 | .99 | .87 | .62 |
| Georgia | 1.50 | 2.22 | .80 | .75 | .50 |
| Nevada, Moapa district | .80 | 1.30 | 1.70 | .84 | .56 |
| North Carolina | .98 | 1.20 | 1.15 | .70 | .60 |
| Oklahoma | .89 | 1.25 | 1.10 | .68 | .55 |
| South Carolina | 1.31 | 1.90 | .75 | .55 | .50 |
| Texas, other than early district | .50 | 1.16 | .95 | .81 | .40 |
| Average | 1.13 | 1.10 | .95 | .84 | .53 |
| Intermediate shipping group: | | | | | |
| Delaware | 1.00 | 1.15 | 1.50 | .75 | .65 |
| Illinois | 1.20 | 1.45 | 1.75 | 1.25 | .80 |
| Indiana | 1.23 | 1.50 | 1.55 | 1.15 | .90 |
| Maryland | 1.21 | 1.45 | 1.55 | .75 | .86 |
| New Mexico | 1.10 | 1.00 | 1.50 | 1.17 | .80 |
| Tennessee | 1.05 | 1.50 | 1.60 | 1.35 | .90 |
| Washington | .61 | .76 | 1.18 | .75 | .60 |
| Average | 1.11 | 1.27 | 1.48 | .93 | .81 |
| Late shipping group: | | | | | |
| Colorado | .94 | .83 | 1.20 | .85 | .70 |
| Iowa | 1.06 | 1.48 | 1.40 | 1.05 | .50 |
| Kansas | .92 | .81 | 1.05 | .80 | .65 |
| Michigan | 1.35 | 1.35 | 1.60 | 1.20 | 1.10 |
| Nevada, other than Moapa district | 1.70 | 1.75 | 1.00 | 1.25 | .50 |
| New Jersey | .95 | 1.25 | 1.25 | 1.00 | .63 |
| Ohio | | 1.75 | 1.85 | 1.09 | .80 |
| Oregon | | 1.00 | 1.25 | .75 | .60 |
| Utah | | | | .55 | .42 |
| Average | 1.02 | .95 | 1.27 | .94 | .73 |
| Average | 1.30 | 1.30 | 1.20 | 1.00 | .83 |

[1] Includes Honey Dew, Honey Ball, casaba, and Persian melons but not watermelons. Prices are based on crates containing about 60 pounds.

Division of Crop and Livestock Estimates.

Table 17 shows the estimated price to growers for crates containing about 60 pounds of cantaloups and other muskmelons. In the Imperial Valley, the average seasonal price to growers for cantaloups and miscellaneous melons considered together ranged, during the 5-year period 1928–32, from $1.63 in 1929 to $1.14 in 1931. For the other districts of California, the range was from $1.06 in 1928 to $0.62 in 1932. There was also a considerable range in average prices paid to growers among other States and districts and for different years in the period. For all States the range was from $1.30 in 1928 and 1929 down to $0.83 in 1932.

Since prices of miscellaneous melons are averaged with prices of cantaloups in the districts that produce them, the table does not afford a comparison of cantaloup prices among all districts.

The Federal-State market news reports afford a means of comparing shipping-point prices in certain important districts and States (table 18). These prices, however, are not an accurate measure of the average prices received for the whole crop since, in many instances, ship-

ments were consigned or sold delivered at market and for some districts and years large quantities were not marketed. Also the prices shown in the table are on a specified size of crate and kind of pack and would not represent the shipping-point price of all melons sold.

TABLE 18.—*Prices per crate of cantaloups at representative shipping districts, 1928–32, and similar prices for Honey Ball and Honey Dew melons, 1930–32*

| Shipping district | Type or variety and basis and unit of sale | Year and period | Price range for period | Price range first week of period | Average shipping point price for period [1] |
|---|---|---|---|---|---|
| | | | *Dollars* | *Dollars* | *Dollars* |
| California, Imperial Valley. | Cantaloups, salmon meat, standard 45s, carloads f.o.b. cash track. | 1928 May 14–July 10 | 1.00–3.50 | 2.00–3.50 | 1.68 |
| | | 1929 May 20–July 11 | .90–4.50 | 2.40–4.50 | 2.03 |
| | | 1930 May 11–July 5 | 1.00–4.25 | 2.50–4.25 | 1.84 |
| | | 1931 May 6–July 7 | .75–4.00 | 2.00–4.00 | 1.24 |
| | | 1932 May 9–July 5 | .65–3.75 | 2.35–3.75 | 1.36 |
| | Honey Ball, standard 45s, carloads f.o.b. cash track. | 1930 June 12–July 25 | 1.00–2.50 | 2.00–2.50 | 1.58 |
| | | 1931 June 3–July 25 | .75–2.50 | 1.75–2.50 | .99 |
| | | 1932 June 2–July 28 | .65–2.75 | 2.00–2.75 | .93 |
| | Honey Dew, standard and jumbo crates, (6¾-inch and 7¾ by 16 by 22½ inches), carloads f.o.b. cash track. | 1930 June 6–July 25 | .75–2.00 | .75–1.75 | 1.16 |
| | | 1931 May 20–July 21 | .45–2.00 | .85–2.00 | .60 |
| | | 1932 June 1–July 18 | .40–2.00 | .85–2.00 | .56 |
| Arizona | Cantaloups, various varieties, standard 45s [2], carloads f.o.b. cash track. | 1928 June 25–July 10 | 1.40–2.15 | 1.40–2.00 | 1.78 |
| | | 1929 June 28–July 24 | 1.15–2.00 | 1.50–2.00 | 1.45 |
| | | 1930 June 24–July 24 | .90–2.25 | 1.50–2.25 | 1.40 |
| | | 1931 June 25–July 13 | .70–1.25 | .75–1.00 | .91 |
| | | 1932 July 5–July 11 | .80–.88 | .80–.88 | .83 |
| Colorado, Rocky Ford. | Cantaloups, salmon and pink meat, standard and jumbo flats, carloads f.o.b. cash track [3] | 1928 Aug. 27–Sept. 22 | .40–1.00 | 1.00 | .67 |
| | | 1929 Aug. 19–Sept. 19 | .35–.70 | .40–.55 | .49 |
| | | 1930 Aug. 18–Sept. 13 | .40–.55 | .45–.55 | .46 |
| | | 1931 Aug. 18–Sept. 12 | .30–.55 | .40–.45 | .39 |
| | | 1932 Aug. 16–Sept. 13 | .30–.40 | .30–.40 | .35 |
| Maryland, Eastern Shore. | Cantaloups, salmon and pink meat, wagon loads cash to growers at auction, crates (mostly 13- and 14-inch square heads) [5]. | 1928 [4] | | | |
| | | 1929 July 31–Aug. 23 | .75–2.25 | .75–2.25 | 1.34 |
| | | 1930 July 26–Aug. 15 | 1.00–3.25 | 1.00–3.25 | 1.87 |
| | | 1931 July 27–Aug. 13 | .30–2.25 | 1.25–2.25 | 1.17 |
| | | 1932 [4] | | | |

[1] Weighted according to daily shipments, using mid point of daily shipping-point price range as daily average price. Since many shipments are not sold on a shipping-point basis and only 1 size of crate and pack is represented, this cannot be considered the average price of all shipments.

[2] Includes some standard 36s in 1928.

[3] In 1928 the quotations were on standard flats, 12s and 15s, and in 1930 sales were "f.o.b. usual terms."

[4] Market news reports were not issued in this district in 1928 or 1932.

[5] Prices from July 31 to Aug. 8, 1929, were quoted f.o.b. usual terms. Some 1931 prices were for crates with 15-inch square heads.

For certain districts, table 18 shows the range in shipping-point prices of specified sizes of crates and packs for the periods shown in the 5 years, 1928–32. The price range for the first week of the period is also shown as these early prices are usually somewhat higher than prices later in the shipping season. The average shipping-point price for the crate and pack specified are also included.

It is apparent that the relationship between cantaloup prices in different districts changes greatly from year to year. The highest average price shown for the period was $2.03 per crate f.o.b., cash track, for salmon meats, standard 45s, in Imperial Valley in 1929. In that year the auction price to growers on the Eastern Shore of Maryland for salmon and pink meats in crates with 13- and 14-inch heads averaged $1.34, but in 1930 the Maryland price of $1.87 was higher than the Imperial Valley price of $1.84.

It is the custom in some important cantaloup districts to use the 45 pack in standard crates as the basis on which cantaloup prices are established. The premium or discount on other packs and sizes of crates varies somewhat from year to year. The relationship in prices of different crates and packs of cantaloups in some western districts in recent years has been approximately as follows: The jumbo 45

pack has usually sold for 15 to 25 cents more and occasionally 50 cents more per crate than the standard 45. The jumbo 36 pack has usually sold at about the same price as the standard 45. The standard 36 has sold at 15 to 25 cents less per crate. The price of pony crates of cantaloups has usually been 70 to 75 percent of the price of standard 45s. However, when a high percentage of the crop is of small or pony size, the pony pack in some years has sold for less than half the price of the standard 45 pack. The price of flats is usually about 40 percent of the price of standard 45s.

The average of shipping-point prices of Honey Dew melons in Imperial Valley was $1.16 in 1930 and only 56 cents in 1932. Honey Ball prices averaged considerably less than cantaloup prices.

There is usually a wide range in prices during the season in any district. For example, in Imperial Valley in 1931, the range in price of salmon meats, standard 45s, f.o.b. cash track, was $0.75 to $4 per crate.

Records of prices of cantaloups, Honey Dews, and Honey Ball melons in the leading markets are available in the files of the Federal Market News Service. The prices are on sales to jobbers usually in lots of 5 to 50 crates.

Table 19 shows average monthly prices for five seasons, 1928–32, in six important markets for cantaloups from a few leading producing districts. The prices shown are unweighted averages of the quoted daily prices on days when sales were reported by the market news service. During the heavy shipping period from any district, sale prices in the markets were reported for practically every market day. At the beginning and end of the shipping seasons, however, some markets reported sales on melons from a certain district for periods of several weeks when other markets did not report sales. In some instances sales were reported for a few days near the beginning or end of the season, then for several days no sales were reported. In instances when sales were reported on less than 6 market days in a month the average price is not shown.

TABLE 19.—*Average monthly cantaloup prices per crate to jobbers, six cities, 1928–32*[1]

CALIFORNIA, SALMON MEAT, STANDARD 45s

| Year and month | Boston | New York | Philadelphia | Pittsburgh | Chicago | St. Louis |
|---|---|---|---|---|---|---|
| 1928: | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| May | 6.02 | 6.39 | 4.82 | 6.02 | 5.34 | 4.81 |
| June | 3.46 | 3.42 | 3.49 | 3.30 | 3.17 | 3.40 |
| July | 3.09 | 2.72 | 2.87 | 2.84 | 2.75 | 3.03 |
| August | 2.56 | | | 2.54 | 2.38 | 2.17 |
| 1929: | | | | | | |
| May | 8.19 | 7.99 | 7.75 | 7.68 | 7.02 | 8.11 |
| June | 5.09 | 4.82 | 4.78 | 4.64 | 4.20 | 4.48 |
| July | 3.16 | 3.04 | 2.90 | 2.89 | 2.81 | 2.84 |
| August | 2.82 | 2.48 | | 2.56 | 2.43 | 2.64 |
| 1930: | | | | | | |
| May | 6.26 | 7.31 | 6.46 | 6.16 | 6.39 | 5.54 |
| June | 3.22 | 3.05 | 3.15 | 3.26 | 3.15 | 3.26 |
| July | 3.42 | 3.20 | 3.12 | 3.02 | 2.77 | 2.79 |
| August | 2.82 | 2.81 | | 2.86 | 2.55 | 2.63 |
| 1931: | | | | | | |
| May | 4.80 | 5.02 | 4.80 | 4.94 | [2] 4.29 | 4.09 |
| June | 2.79 | 2.72 | 2.81 | 2.65 | 2.50 | 2.58 |
| July | 2.45 | 2.65 | 2.44 | 2.46 | 2.11 | 2.35 |
| August | 2.38 | 2.26 | | 2.49 | 1.86 | |
| 1932: | | | | | | |
| May | 4.58 | 5.55 | 4.52 | 4.75 | 4.20 | 4.06 |
| June | 2.72 | 2.73 | 2.81 | 2.63 | 2.60 | 2.70 |
| July | [2] 2.46 | 2.31 | 2.36 | 2.24 | [2] 1.95 | [2] 2.18 |
| August | 1.91 | [2] 2.02 | | 1.91 | | |

[1] Prices are unweighted averages of daily market news quotations, on stock of good quality and condition, on days when prices were reported. Does not include prices of "vine-ripened and precooled stock."

[2] From market news data but not from records of Division of Statistical and Historical Research.

TABLE 19.—*Average monthly cantaloup prices per crate to jobbers, six cities, 1928–32* [1]—Continued

ARIZONA, SALMON MEAT, STANDARD 45s

| Year and month | Boston | New York | Philadelphia | Pittsburgh | Chicago | St. Louis |
|---|---|---|---|---|---|---|
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| 1928, July | 3.09 | 2.64 | 2.78 | 2.88 | 2.53 | 2.76 |
| 1929, July | 2.90 | 2.97 | 2.73 | 2.81 | 2.76 | 2.92 |
| 1930, July | 2.94 | 2.92 | 2.77 | 2.86 | 2.58 | 2.65 |
| 1931, July | 2.34 | 2.39 | 2.41 | 2.26 | 2.07 | 2.03 |
| 1932, July | 1.86 | 2.01 | 2.31 | 2.09 | 1.85 | 2.02 |

COLORADO, SALMON MEAT, STANDARD FLATS 12s AND 15s

| | | | | | | |
|---|---|---|---|---|---|---|
| 1928, September | 1.30 | [2] 1.02 | 1.08 | 1.08 | 0.93 | 1.00 |
| 1929, September | 1.03 | .93 | .98 | .97 | .79 | [2] .87 |
| 1930: | | | | | | |
| August | .89 | .81 | .76 | .92 | .79 | .72 |
| September | .71 | .62 | .63 | .67 | .56 | .56 |
| 1931: | | | | | | |
| August [2] | .87 | .81 | .68 | .82 | .58 | .52 |
| September [2] | .82 | .85 | .90 | .73 | .61 | .50 |
| 1932: | | | | | | |
| August | .69 | .50 | | [2] .56 | .45 | [2] .45 |
| September | .62 | .67 | .69 | [2] .63 | .52 | [2] .64 |

DELAWARE AND MARYLAND, VARIOUS VARIETIES [3]

| | | | | | | |
|---|---|---|---|---|---|---|
| 1928, August [4] | | | | | | |
| 1929, August [2] | 1.28 | 1.32 | 0.87 | 1.43 | | |
| 1930, August [2] | 1.95 | 1.70 | 1.35 | 1.97 | | |
| 1931, August [2] | 1.00 | .85 | .69 | 1.25 | | |
| 1932, August [4] | | | | | | |

[1] Prices are unweighted averages of daily market news quotations, on stock of good quality and condition.
[2] From market news data but not from records of Division of Statistical and Historical Research.
[3] August 1929—Boston, New York, Philadelphia, Pittsburgh, standard 36s and 45s; August 1930—Boston, standard 45s; New York and Philadelphia, standard 36s; and Pittsburgh, standard 36s and 45s; August 1931—New York, standard 36s; Boston, Philadelphia, and Pittsburgh, standard 36s and 45s.
[4] No market news reports were issued in this district in 1928 and 1932.

Compiled by Division of Statistical and Historical Research except figures indicated by footnote 2.

For the 5-year period in each of the six markets—Boston, New York, Philadelphia, Pittsburgh, Chicago, and St. Louis—the price of California cantaloups trended downward through the season from May to August.

The variations in these prices among the different cities for any month are due chiefly to differences in supply and demand. In some months, particularly at the beginning and end of the season, the average prices are based on quotations for only a short period.

On the whole, the prices of western cantaloups in the midwestern markets, Chicago and St. Louis, have averaged somewhat lower than in the eastern markets. This does not necessarily mean that returns to growers have averaged less on shipments to these markets, since transportation charges are lower.

Prices paid in the eastern markets for Delaware and Maryland cantaloups were considerably less than those paid for western cantaloups (table 19).

Table 20 shows average monthly prices in Chicago, when available in the period 1928–32, for cantaloups from Arkansas, Indiana, Michigan, and New Mexico. Prices of North Carolina cantaloups in New York and Philadelphia are also included. Average market prices of standard crates of cantaloups from these States in the 5 years, according to the tabulation, varied from 88 cents to $2.29. A comparison

of prices in table 20 with those in table 19 shows that cantaloups from the Midwestern and Eastern States sold at considerably lower prices than western cantaloups in the large markets.

TABLE 20.—*Average price per crate to jobbers for cantaloups from specified States in specified markets by months, 1928–32* [1]

| State of origin | Type and pack | Market | Month | 1928 | 1929 | 1930 | 1931 | 1932 |
|---|---|---|---|---|---|---|---|---|
| | | | | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| Arkansas | Salmon meat, standard 36s and 45s. | Chicago | July | 1.28 | 2.41 | 2.29 | 1.67 | 1.24 |
| | | | August | ------ | ------ | 1.88 | 1.01 | ------ |
| Indiana | Pink meat and salmon meat, standard 36s and 45s. | Chicago | July | ------ | ------ | 1.96 | ------ | 1.20 |
| | | | August | 1.73 | 1.90 | ------ | 1.10 | 1.23 |
| Michigan | Crates with 12 by 12 inch heads. | Chicago | August | [2] 1.63 | [2] 2.03 | [2] 1.31 | [3] 1.41 | [4] 1.15 |
| | | | September | ------ | [2] 2.04 | [2] 1.29 | [5] 1.38 | [4] .90 |
| New Mexico | Pink meat, standard flats 12s and 15s. | Chicago | July | ------ | ------ | ------ | 1.08 | ------ |
| | | | August | 1.25 | 1.00 | .89 | .81 | [6] .80 |
| North Carolina | Salmon meat, standards, all sizes. | New York | July | ------ | 1.41 | ------ | 1.27 | 1.18 |
| | | Philadelphia | do | .88 | ------ | ------ | ------ | .97 |

[1] Prices are unweighted averages of daily market news quotations, on stock of good quality and condition, on days when prices were reported.
[2] Quotations are on Osage variety only.
[3] Quotations are on Hearts of Gold variety only.
[4] Quotations are on Hearts of Gold in crates with 11- by 11-inch and 12- by 12-inch heads.
[5] Quotations are on Honey Rock and Hoodoo in crates with 11- by 11-inch and 12- by 12-inch heads.
[6] Quotations are on jumbo flats, 9s to 15s.

There has been considerable variation in the average monthly prices of Honey Dew and Honey Ball melons in the various markets. In the 5-year period, the highest average monthly price for Honey Dew melons in the six markets was in New York in June 1929 when the average was $4.34 per crate (table 21) The highest price for Honey Ball melons in standard cantaloup crates was also in New York in June 1929 when the price averaged $6.68 (table 22). The June prices on both Honey Dew and Honey Ball melons in the various markets were higher than the July and August prices. For Honey Dew, many of the July and August market prices during the 5-year period ranged roughly from $1.50 to $2.50 per crate. For Honey Ball in standard cantaloup crates, many of the July and August average prices were between $2 and $3.50.

TABLE 21.—*Average price per standard crate to jobbers for California Honey Dew melons, six cities, by months, 1928–32* [1]

| Month and year | Boston | New York | Philadelphia | Pittsburgh | Chicago | St. Louis |
|---|---|---|---|---|---|---|
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| June 1928 | 2.27 | 3.02 | 2.41 | 2.17 | 2.28 | 2.30 |
| July 1928 | [2] 1.63 | 1.68 | 1.72 | 1.50 | 1.57 | 1.56 |
| August 1928 | [2] 1.73 | 1.45 | [2] 1.64 | 1.60 | 1.65 | [2] 1.59 |
| June 1929 | 3.32 | 4.34 | 3.93 | 3.33 | 3.16 | ------ |
| July 1929 | [2] 1.84 | 1.68 | 1.73 | 1.73 | 1.74 | 1.70 |
| August 1929 | [2] 2.14 | 2.19 | [2] 2.24 | [2] 2.28 | 2.17 | 2.13 |
| June 1930 | 2.88 | 3.41 | 3.01 | 2.57 | 2.91 | 2.74 |
| July 1930 | 2.51 | 2.67 | 2.68 | 2.61 | 2.34 | 2.37 |
| August 1930 | [2] 1.43 | [2] 1.67 | [2] 1.53 | [2] 1.53 | 1.21 | 1.57 |
| June 1931 | 1.91 | 2.34 | 2.01 | 1.88 | [2] 2.01 | 1.67 |
| July 1931 | [2] 1.25 | 1.38 | 1.30 | 1.32 | [2] 1.26 | 1.30 |
| August 1931 | 1.53 | [2] 1.68 | [2] 1.53 | [2] 1.64 | [2] 1.55 | 1.49 |
| June 1932 | 2.28 | 2.52 | 2.42 | 1.83 | 1.99 | 1.78 |
| July 1932 | [2] 1.37 | [2] 1.38 | [2] 1.42 | 1.28 | 1.26 | 1.27 |
| August 1932 | [2] 1.50 | [2] 1.51 | [2] 1.49 | 1.45 | 1.36 | [2] 1.31 |

[1] Prices are unweighted averages of daily market news quotations, on stock of good quality and condition, on days when prices were reported. Approximate dimensions of the standard crates are 6¾ by 16 by 22⅛ inches.
[2] Includes some quotations on jumbo crates with approximate dimensions 7¾ by 16 by 22⅛ inches.

TABLE 22.—*Average price per crate to jobbers for California Honey Ball melons, standard 36s and 45s, six cities, by months, 1928–32* [1]

| Month and year | Boston | New York | Philadelphia | Pittsburgh | Chicago | St. Louis |
|---|---|---|---|---|---|---|
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| June 1928 | | 4.91 | 4.10 | | | |
| July 1928 | 2.82 | 3.34 | 3.22 | 2.40 | [2] 3.00 | 3.06 |
| August 1928 | 2.50 | 2.25 | 1.84 | 2.28 | [2] 2.24 | 2.30 |
| June 1929 | | 6.68 | 5.60 | | | |
| July 1929 | 3.14 | 3.14 | 3.27 | 3.17 | 3.10 | 2.97 |
| August 1929 | 3.83 | 3.94 | 3.84 | 3.03 | 3.54 | 3.78 |
| June 1930 | 4.50 | [2] 5.89 | [3] 4.85 | [2] 4.12 | [3] 4.05 | |
| July 1930 | [2] 3.24 | 3.62 | [2] 3.44 | [2] 3.52 | [2] 2.96 | 3.13 |
| August 1930 | 2.47 | 2.48 | 2.45 | [2] 2.49 | [2] 2.32 | 2.61 |
| June 1931 | [3] 2.97 | [3] 4.32 | 3.61 | [3] 3.23 | 3.09 | [2] 3.06 |
| July 1931 | [3] 1.97 | [2] 2.16 | [3] 2.22 | [3] 2.04 | [2] 2.04 | 2.25 |
| August 1931 | [2] 2.03 | [2] 2.67 | [3] 2.01 | 2.05 | [3] 1.75 | 2.55 |
| June 1932 | [3] 2.85 | [3] 4.16 | [3] 3.62 | [3] 3.16 | [2] 2.79 | [3] 2.96 |
| July 1932 | [3] 2.39 | [3] 2.52 | [3] 2.63 | [3] 2.32 | [3] 2.07 | [3] 2.29 |
| August 1932 | | [3] 2.50 | [3] 2.27 | [3] 2.02 | [3] 1.93 | [3] 2.11 |

[1] Prices are unweighted averages of daily market news quotations, on stock of good quality and condition, on days when prices were reported.
[2] Mostly 45s.
[3] Quotations are on standard 45s only.

The average monthly price of California casaba melons in standard and jumbo crates at New York ranged during the period July to October, 1928–32 from $1.34 to $2.35 (table 23). For each of the years 1928, 1929, and 1930, the highest monthly price occurred in August. In 1931, the highest price was in October, and in 1932 in July.

TABLE 23.—*Average price per crate to jobbers for California casaba melons, at New York City, by months, 1928–32* [1]

| Year | July | August | September | October |
|---|---|---|---|---|
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| 1928 | 1.34 | 1.79 | 1.50 | 1.68 |
| 1929 | 2.22 | 2.35 | 1.71 | 1.83 |
| 1930 | 1.88 | 2.15 | 1.83 | 1.72 |
| 1931 | 1.60 | 1.42 | 1.60 | 1.78 |
| 1932 | 1.80 | 1.43 | 1.36 | 1.36 |

[1] Prices are unweighted averages of daily market news quotations, on days when prices were reported, for stock of good quality and condition, in standard and jumbo crates with various numbers of melons per crate.

During the principal marketing period for Persian melons, August to October in the years 1928 to 1932, the average monthly price to jobbers in New York ranged from $1.17 to $2.94 per standard crate. In 1928 the highest average monthly price was in October; in 1929 it was in August, and in 1931 in September. The average monthly prices of jumbo crates of Persian melons ranged from 3 to 34 cents higher than the price of standard crates and averaged 20 cents higher (table 24).

TABLE 24.—*Average price per crate to jobbers for California Persian melons, at New York City, by months, 1928–32* [1]

| Year | Standard crates containing various numbers of melons [2] | | | Jumbo crates containing various numbers of melons [2] | | |
|---|---|---|---|---|---|---|
| | August | September | October | August | September | October |
| | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* | *Dollars* |
| 1928 | 1.65 | 2.11 | 2.74 | 1.99 | 2.43 | 2.95 |
| 1929 | 2.94 | 1.35 | 1.17 | 3.12 | 1.54 | 1.20 |
| 1930 | 1.68 | 1.69 | 1.94 | 1.99 | 2.03 | 2.09 |
| 1931 | 1.65 | 2.02 | 1.78 | 1.76 | 2.14 | 2.02 |
| 1932 | 1.80 | 1.67 | 1.88 | 1.90 | 1.80 | 2.12 |

[1] Prices are unweighted averages of daily market news quotations, on stock of good quality and condition, on days when prices were reported.
[2] For dimensions of crates, see table 11.

## COMPETITION WITH OTHER FRUITS AND MELONS

The principal part of the marketing season for cantaloups and other muskmelons is from May through September. During this period many other fruits and watermelons are on the markets in large volume.

Average car-lot shipments by months from May to September for the period 1930–32 for 14 different melons and fruits and for mixed carloads of melons, citrus fruits, and deciduous fruits are shown in table 25.

The total average monthly car-lot shipments of these commodities in round numbers were 18,000 cars in May, 38,000 in June, 60,000 in July, 50,000 in August, and 52,000 in September. Of the May total, cantaloups made approximately one fourth, while in September cantaloups made only about 2 percent of the total. The June car-lot shipments of cantaloups were greater than in any other month. These car-lot shipment figures do not represent the total movement to market since large quantities go by truck. Beginning in July there are large quantities of cantaloups and various fruits trucked to market from some of the Eastern and Midwestern States, so that the car-lot shipment figures for July and later months are much smaller than the actual volume marketed. The figures do, however, give a general idea of the volume and kind of competition encountered in marketing cantaloups and other melons.

The principal fruits that compete with cantaloups in May are oranges, apples, and grapefruit. In June, watermelons, oranges, plums, and fresh prunes, and peaches compete strongly. In July, watermelons, peaches, oranges, pears, and apples are the leading competitors. Peaches, watermelons, pears, oranges, grapes, and apples are on the markets in heavy supply in August, and in September, grapes and apples are in heaviest supply among the fruits, followed by pears, peaches, and oranges (table 25).

TABLE 25.—*Car-lot shipments by months (May–September) of cantaloups, Honey Ball, Honey Dew, and other specified melons and competing fruits, United States, 3-year average, 1930–32*

| Commodity | May | June | July | August | September |
|---|---|---|---|---|---|
| | *Cars* | *Cars* | *Cars* | *Cars* | *Cars* |
| Cantaloups | 4,649 | 7,469 | 5,699 | 2,758 | 1,146 |
| Honey Ball melons | 2 | 507 | 1,543 | 251 | 52 |
| Honey Dew melons | 32 | 1,327 | 1,747 | 961 | 1,246 |
| Casaba melons | 0 | 14 | 26 | 19 | 29 |
| Persian melons | 0 | 2 | 51 | 153 | 90 |
| Mixed melons | 101 | 1,185 | 421 | 306 | 356 |
| Apples | 2,152 | 1,247 | 3,029 | 2,199 | 11,695 |
| Cherries | 628 | 958 | 528 | 34 | 2 |
| Grapefruit | 1,572 | 530 | 159 | 99 | 498 |
| Oranges | 7,651 | 5,005 | 5,470 | 4,188 | 4,004 |
| Mixed citrus fruits | 450 | 291 | 237 | 154 | 114 |
| Grapes | 0 | 193 | 1,252 | 3,996 | 16,044 |
| Mixed deciduous fruits | 114 | 598 | 1,076 | 1,402 | 849 |
| Peaches | 22 | 1,639 | 10,838 | 16,666 | 5,622 |
| Pears | 101 | 314 | 3,799 | 6,552 | 6,580 |
| Plums and fresh prunes | 215 | 1,844 | 1,398 | 1,465 | 1,990 |
| Watermelons | 401 | 15,215 | 22,236 | 8,640 | 1,211 |
| Total | 18,090 | 38,338 | 59,509 | 49,843 | 51,528 |

The Honey Ball and Honey Dew shipments are heaviest in July which is the month of the period May to September in which the car-lot movement to market of the leading fruits and melons is greatest.

Prospects are for continued strong competition among the various melons and fruits.

## SUMMARY

The popularity and commercial importance of various varieties of cantaloups have changed rapidly during recent years. Efforts are being made to develop varieties and methods of handling which will result in improvement of the quality of melons on the markets. Many cantaloups of poor quality, due to immaturity or other causes, arrive on the markets each year. A general improvement in quality would undoubtedly increase the demand for cantaloups. Much improvement in the average quality and condition of cantaloups on the markets is possible through correct harvesting, grading, packing, and shipping methods. Prices show that cantaloups of the best quality and condition command a considerable premium over stock handled by the usual methods.

The production of miscellaneous muskmelons, particularly Honey Ball and Honey Dew, has increased rapidly in the last decade. About three fourths of the commercial crop of cantaloups and miscellaneous muskmelons is produced in three Western States: California, Arizona, and Colorado. California alone produces more than half the commercial crop.

Car-lot shipments of cantaloups in the United States approximated 30,000 cars in 1925 and 1927. There is also considerable movement to market by motor truck. The principal shipping season for cantaloups is from May to September inclusive.

The movement to market of miscellaneous muskmelons is somewhat later than that of cantaloups from the same district. For the period 1930–32 the car-lot shipments of Honey Dew, Honey Ball, and other miscellaneous muskmelons approximated one half the volume of cantaloup shipments.

Various methods of sale are used in marketing the melon crop. Large quantities of western melons are sold at shipping point f.o.b. cash track. In some districts truckers buy large quantities, and some melons are sold at roadside stands. In the city markets many of the cantaloups and miscellaneous muskmelons go through the regular wholesale and jobbing trade. In a few large cities considerable quantities are sold through the auctions.

The western crop is widely distributed throughout the United States. The eastern, southern, and midwestern crops have a more limited market distribution.

Prices vary considerably in different years and in different markets. The average price to growers per standard cantaloup crate for cantaloups and other muskmelons was estimated at $1.30 in both 1928 and 1929, then declined each year until 1932 when the price averaged 83 cents.

There is keen competition on the markets among the various fruits and melons, and prospects are for continued strong competition.

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# INFLUENCE OF STORAGE TEMPERATURES ON THE REST PERIOD AND DORMANCY OF POTATOES

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## INTRODUCTION

Under ordinary storage conditions potatoes will not sprout for some time after being dug. This period of apparent inactivity is commonly known as the rest period. Appleman[1] says, in writing about certain laboratory experiments, this "period varies in different varieties but is quite constant in any given variety. When a few tubers of a lot begin to sprout, it is a matter of a few days until all will sprout."

It is of importance both to the grower and the storage man interested in the keeping of potatoes in a dormant condition either for eating stock or for seed, to know how long he may expect to hold potatoes of a given variety in the desired dormant condition. From a marketing point of view sprouted potatoes are undesirable. They are not desired for food, and the commercial seed dealer does not wish to handle them because the sprouts break off in handling and growers doubt the value of such seed after the first sprouts have broken off. Appleman,[2] however, found that breaking off one or two crops of sprouts has no injurious effects so long as other conditions are kept favorable. When seed stock has reached the sprouting stage the tubers sometimes tend to become soft and shriveled and so less desirable.

There is some confusion as to the meaning of the terms "dormant period" and "rest period." In this discussion, the term "rest period" in potato tubers refers to that period immediately following harvest during which they will not sprout even when kept under

[1] APPLEMAN, C. O. STUDY OF REST PERIOD IN POTATO TUBERS. Md. Agr. Expt. Sta. Bull. 183, pp. 181–226, illus. 1914.

[2] APPLEMAN, C. O. POTATO SPROUTS AS AN INDEX OF SEED VALUE. Md. Agr. Expt. Sta. Bull. 265, pp. 237–258, illus. 1924.

favorable growing conditions. Under the same conditions at the end of this rest period growth activity evidenced by the production of sprouts becomes apparent. On the other hand, if potatoes are held at a temperature too low for sprout growth they will remain in a dormant condition until they break down physiologically. If these potatoes are subjected to conditions favorable for growth at any time after the rest period is over and before this physiological break-down takes place, they will sprout. The rest period of potatoes is therefore determined largely by inherent factors, whereas dormancy is dependent upon both inherent and external factors.

Much is to be found in the literature concerning the many causal factors related to the rest or dormant periods in potatoes or other plants; hence this phase of the subject will not be discussed at length. Müller-Thurgau [3] was one of the early investigators interested in the underlying causes of the rest period of potatoes. He concluded that conditions causing the formation of diastase marked the end of the rest period. He found no diastase in resting potatoes but always found it in sprouting potatoes.

Considerable investigation of artificial methods for shortening the natural rest period for commercial purposes has also been conducted recently, and the results have been published.[4]

## EXPERIMENTAL STUDIES

The purpose of the present investigation was to determine the extent to which the range of the controlled storage or holding temperatures most frequently met with in the ordinary commercial handling of potatoes influenced the duration of the rest and dormant periods. The plan did not include the use of chemicals or of wounding practices or any other treatment to break the rest period.

In order to eliminate as far as possible complicating extraneous factors the potatoes used in the tests were grown and stored on the Arlington Experiment Farm at Rosslyn, Va. The varieties studied included the Irish Cobbler, Triumph, Early Rose, Spaulding Rose, Green Mountain, and Russet Rural, and all were from selected seed stock. The work was started in 1925 and continued through 1927. Each year two crops from each variety, consisting of an early and a late planting, were utilized. The early crop was planted in April and the late one in July of each year. Two harvestings were made from each planting. The first consisted of immature stock dug at the first signs of normal yellowing and dying of the tips and edges of the leaves, which is usually considered an indication of approaching maturity, and the second consisted of mature stock dug after the vines were entirely dead and the skins of the tubers well "set" so that they would not readily rub off when handled. The immature tubers were harvested on an average of about 2 weeks in advance of the mature potatoes. The mature tubers of the early crop were usually harvested in July or August, depending on the growing season and the variety, whereas the late mature crop usually was dug

[3] MÜLLER-THURGAU, H. UEBER ZUCKERANHÄUFUNG IN PFLANZENTHEILEN IN FOLGE NIEDERER TEMPERATUR. Landw. Jahrb. 11: [751]–828. 1882.

[4] DENNY, F. E. HASTENING THE SPROUTING OF DORMANT POTATO TUBERS. Amer. Jour. Bot. 13: 118–125. 1926.

——— SECOND REPORT ON THE USE OF CHEMICALS FOR HASTENING THE SPROUTING OF DORMANT POTATO TUBERS. Amer. Jour. Bot. 13: 386–396. 1926.

STUART, W., and MILSTEAD, E. H. BREAKING THE REST PERIOD OF THE POTATO. Proc. 18th Annual Meeting Potato Assoc. of Amer., p. 20–30. 1931.

in early November. Thus there were four lots each year consisting of an immature and a mature crop from both early and late plantings of each of the six varieties.

The potatoes were graded by hand 3 to 4 days after digging, and a selection of nearly uniform medium-sized tubers was made, these being divided into sublots of about a bushel each for storage. The storage temperatures were held constantly at 36°, 40°, 50°, 60°, and 70° F., with relative humidities of 85 to 90 percent. The lots were put in storage within 3 to 4 days after being dug. Every week or two, samples of 10 tubers from each lot of potatoes held at each temperature were selected at random and transferred in 4-quart veneer baskets to a room (hereafter referred to as the sprouting room) held at a constant temperature of 70° with a relative humidity of about 90 percent. Preliminary tests comparing potatoes held as described in the sprouting room, with those covered with moss and wet sand, showed no difference in time for the appearance of sprouts. At weekly intervals after these samples had been placed in the sprouting room a count was made of the tubers showing definite sprouts. The rest period was regarded as completed for any tuber when a single sprout was visible. The selecting of samples from each lot and placing them in the sprouting room was continued until all 10 tubers germinated within 2 weeks. When this was accomplished it was arbitrarily assumed that the rest period of the particular lot of potatoes being sampled was at an end.

### REST PERIODS AT DIFFERENT STORAGE TEMPERATURES

The sampling, as already described, started about 2 weeks after the beginning of the storage periods, but in most instances no sprouting was evident after this storage period plus the additional 2 weeks' period in the sprouting room. Since the aim was to determine after what period of storage at a given temperature all the specimens in a sample would germinate within 2 weeks when kept in the sprouting room, regular periodic sampling was not initiated until it seemed that the end of the rest period was approaching.

Table 1 shows the percentage of germination in the successive samplings of all lots held at the different storage temperatures after 2 weeks in the sprouting room.

TABLE 1.—*Percentage of tubers from early and late-planted and mature and immature dug crops, showing sprouts after 2 weeks in the sprouting room (70° F.) following increasing periods in storage at different temperatures*

IRISH COBBLER

| When planted | Degree of maturity when dug | Storage temperature | Sprouting after 2 weeks at 70° F. plus number of weeks in storage | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | ° F. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. |
| Early 1926 | Mature | 36 | | | 0 | | 0 | | | 0 | | 0 | 10 | (1) | | | | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | 10 | | 10 | 90 | 100 | | | |
| Early 1927 | do | | | | | | | | | 10 | | 100 | | | | | | | |
| Late 1927 | do | | | | | | 0 | | 0 | | 0 | 0 | 60 | 60 | | 100 | | | |
| Late 1926 | Immature | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 100 | | | |
| Late 1927 | do | | | | 0 | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20 | 100 | | | |
| Early 1925 | Mature | 40 | | 35 | | | | 70 | | 90 | | 100 | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 0 | | | 0 | | 10 | | 10 | | 100 | | | | |
| Early 1926 | do | | | | 0 | | 0 | | | 10 | 100 | | | | | | | | |
| Late 1926 | do | | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 10 | 100 | | | | |
| Early 1927 | do | | | | | | | | 0 | 0 | 0 | 100 | | | | | | | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 0 | | 40 | | 40 | | | | 60 | | 100 | | | |
| Late 1925 | do | | 0 | 0 | | | | 0 | | 0 | | | 0 | | 0 | | 100 | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | 0 | | 0 | 10 | 50 | 70 | 100 | |
| Late 1927 | do | | | | 0 | | | 0 | | 0 | | 0 | | 0 | 80 | 100 | | | |
| Early 1925 | Mature | 50 | | 50 | | | | 80 | | 100 | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 10 | | | 60 | | 90 | | 100 | | | | | | |
| Early 1926 | do | | | | 0 | | 0 | | | 30 | 60 | 100 | | | | | | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | 0 | 0 | 90 | 100 | | | | | |
| Early 1927 | do | | | | | | | 0 | 0 | 70 | | 90 | 100 | | | | | | |
| Late 1927 | do | | | | | | 0 | | 0 | 20 | 30 | 30 | 90 | 100 | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 0 | | 30 | | 70 | | | | 100 | | | | | |
| Late 1925 | do | | 0 | 0 | | | | 0 | | 10 | | | 50 | | 100 | | | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | 0 | | 0 | 10 | 50 | 70 | 100 | |
| Late 1927 | do | | | | 0 | | | 0 | | 0 | 10 | 20 | | 50 | 80 | 80 | 100 | | |
| Early 1925 | Mature | 60 | | 25 | | | | 60 | | 100 | | | | | | | | | |
| Late 1925 | do | | | 0 | | | | | 100 | | | | | | | | | | |
| Early 1926 | do | | | | 0 | | 0 | | | 50 | 80 | 80 | 100 | | | | | | |
| Late 1926 | do | | | | | 0 | | 10 | 40 | 60 | 100 | | | | | | | | |
| Early 1927 | do | | | | 0 | 0 | 0 | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | | | 60 | 80 | 100 | | | | | | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 0 | | 40 | | 50 | | | | 100 | | | | | |
| Late 1925 | do | | 0 | 0 | | | | 0 | | 0 | | | 75 | 100 | | | | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | 0 | 40 | 40 | 100 | | | | |
| Late 1927 | do | | | | 0 | | | 10 | | 80 | 100 | | | | | | | | |

## TRIUMPH

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early 1926 | Mature | 36 | | | 0 | | 0 | | | 60 | 30 | 0 | 10 | (1) | | | | | |
| Late 1926 | do | | | | | 0 | 0 | 20 | 0 | 10 | 30 | 30 | 90 | 100 | | | | | |
| Early 1927 | do | | | | | 0 | 0 | 20 | 30 | 90 | 100 | | | | | | | | |
| Late 1927 | do | | | | | | | | | 10 | 20 | | 100 | | | | | | |
| Late 1926 | Immature | | | | 0 | | | 0 | 0 | 10 | 20 | 70 | 20 | (1) | | | | | |
| Late 1927 | do | | | 0 | | | | 0 | 0 | 0 | 0 | 10 | 10 | 100 | | | | | |
| Early 1925 | Mature | 40 | 20 | | | | | 50 | | 100 | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 0 | | | 0 | | 0 | | 10 | | 100 | | | | |
| Early 1926 | do | | | | 0 | | 0 | | | 10 | 90 | 100 | | | | | | | |
| Late 1926 | do | | | | | 0 | | 0 | 10 | 10 | 10 | 10 | 90 | 90 | 100 | | | | |
| Early 1927 | do | | | | | | | 0 | 0 | 70 | 100 | | | | | | | | |
| Late 1927 | do | | | | | | | 0 | 0 | 0 | 10 | 20 | | 50 | 100 | | | | |
| Early 1925 | Immature | | 0 | 0 | | 10 | | 50 | | 80 | | | | 90 | 100 | | | | |
| Late 1925 | do | | 0 | 0 | | | | 0 | | 0 | | | 0 | | 0 | | 0 | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | | 0 | | 0 | 0 | 0 | 10 | 100 |
| Late 1927 | do | | | | 0 | | | 0 | | 0 | 0 | 10 | | 10 | 20 | 100 | | | |
| Early 1925 | Mature | 50 | 70 | | | | | 70 | | 100 | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 0 | | | 0 | | 50 | | 100 | | | | | | |
| Early 1926 | do | | | | 0 | | 0 | | | 40 | 80 | 100 | | | | | | | |
| Late 1926 | do | | | | | 0 | 0 | 20 | 20 | 30 | 90 | 100 | | | | | | | |
| Early 1927 | do | | | | | 0 | 0 | 30 | 50 | 100 | | | | | | | | | |
| Late 1927 | do | | | | | | 0 | 0 | 10 | 100 | | | | | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 0 | | 40 | | 80 | | | | 100 | | | | | |
| Late 1925 | do | | 0 | 0 | | | | 0 | | 0 | | 0 | | | 10 | | 60 | 100 | |
| Late 1926 | do | | | 0 | | 0 | | 0 | | 0 | 0 | 10 | 90 | 100 | | | | | |
| Late 1927 | do | | | | 0 | | | 0 | 0 | 90 | 100 | | | | | | | | |
| Early 1925 | Mature | 60 | 90 | | | | | 90 | | 100 | | | | | | | | | |
| Late 1925 | do | | 0 | | 0 | | | | 100 | | | | | | | | | | |
| Early 1926 | do | | | 0 | | 0 | | | | 60 | 80 | 100 | | | | | | | |
| Late 1926 | do | | | | 0 | 0 | 80 | 90 | 100 | | | | | | | | | | |
| Early 1927 | do | | | | 0 | 0 | 100 | | | | | | | | | | | | |
| Late 1927 | do | | | | | 90 | 80 | 100 | | | | | | | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 0 | | 40 | | 70 | | | | 100 | | | | | |
| Late 1925 | do | | 0 | 0 | | 0 | | 0 | | 0 | | | 25 | 100 | | | | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | 10 | 40 | 100 | | | | | | |
| Late 1927 | do | | | 0 | | | | 60 | | 60 | 100 | | | | | | | | |

[1] Tubers were injured by this storage temperature in some samples as the storage time was increased.

TABLE 1.—*Percentage of tubers from early and late-planted and mature and immature dug crops, showing sprouts after 2 weeks in the sprouting room (70° F.) following increasing periods in storage at different temperatures*—Continued

EARLY ROSE

| When planted | Degree of maturity when dug | Storage temperature | Sprouting after 2 weeks at 70° F. plus number of weeks in storage | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | ° F. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. |
| Early 1926 | Mature | 36 | 0 | 0 | 60 | 90 | 100 | | | | | | | | | | | | |
| Late 1926 | do | | 0 | | 0 | 30 | 70 | 80 | 50 | | 90 | 100 | | | | | | | |
| Early 1927 | do | | | | 20 | 30 | 30 | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | 40 | 60 | 70 | 70 | 60 | 100 | | | | | | | | | |
| Late 1926 | Immature | | | | | 0 | 0 | 0 | 0 | | 0 | 20 | 70 | 70 | | 100 | | | |
| Late 1927 | do | | | | 0 | | | 0 | 0 | 0 | 10 | 100 | | | | | | | |
| Early 1925 | Mature | 40 | 20 | 80 | | 100 | | | | | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 20 | | | 100 | | | | | | | | | | |
| Early 1926 | do | | | | 30 | 80 | 100 | | | | | | | | | | | | |
| Late 1926 | do | | | | 0 | 0 | 0 | 80 | 80 | | 90 | 100 | | | | | | | |
| Early 1927 | do | | 20 | | 50 | | 90 | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | 40 | 20 | 50 | 90 | 90 | 90 | 100 | | | | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 25 | | 50 | | 70 | | 100 | | | | | | | |
| Late 1925 | do | | 0 | 0 | | | | 0 | | 0 | | | 10 | | 90 | 100 | | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | 10 | 30 | 40 | | 100 | | | |
| Late 1927 | do | | | | 0 | | | 50 | | 50 | 60 | 100 | | | | | | | |
| Early 1925 | Mature | 50 | 60 | 60 | | 100 | | | | | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 50 | | | 100 | | | | | | | | | | |
| Early 1926 | do | | | | 20 | 90 | 100 | | | | | | | | | | | | |
| Late 1926 | do | | | | 0 | 90 | 90 | 100 | | | | | | | | | | | |
| Early 1927 | do | | | 20 | 40 | | 40 | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | 30 | 30 | 60 | 100 | | | | | | | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 10 | | 70 | | 100 | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | | | 0 | | 40 | | | 50 | | 100 | | | | |
| Late 1926 | do | | | | | 0 | | 0 | 0 | 0 | 70 | 80 | 80 | 90 | 100 | | | | |
| Late 1927 | do | | | | 0 | | | 50 | | 50 | 100 | | | | | | | | |
| Early 1925 | Mature | 60 | 30 | 50 | | 90 | 100 | | | | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 100 | | | | | | | | | | | | | |
| Early 1926 | do | | | | 90 | 90 | 100 | | | | | | | | | | | | |
| Late 1926 | do | | | | 100 | | | | | | | | | | | | | | |
| Early 1927 | do | | | 30 | 50 | 60 | 60 | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | 100 | | | | | | | | | | | | | | |
| Early 1925 | Immature | | 0 | 0 | | 20 | | 60 | | 90 | | 100 | | | | | | | |
| Late 1925 | do | | | | | | | 0 | | 90 | | 100 | | | | | | | |
| Late 1926 | do | | | | | | 0 | | 0 | | 60 | 100 | | | | | | | |
| Late 1927 | do | | | | | 0 | | 90 | 100 | | | | | | | | | | |

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early 1926 | Mature | 36 | | | 20 | 60 | 90 | 100 | | | | | | | | | | | | |
| Late 1926 | do | | | | 0 | 0 | 20 | 70 | 70 | | 70 | 100 | | | | | | | | |
| Early 1927 | do | | | 0 | 10 | 30 | 30 | | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | 0 | 0 | 30 | 50 | 50 | | 80 | 100 | | | | | | | | |
| Late 1926 | Immature | | | | 0 | 0 | 0 | 0 | | 0 | | 0 | | 0 | 30 | 40 | 60 | 100 | | |
| Late 1927 | do | | | | 0 | | | 0 | 0 | 0 | 10 | 10 | 10 | 90 | 100 | | | | | |
| Early 1925 | Mature | 40 | 10 | 40 | 100 | | | | | | | | | | | | | | | |
| Late 1925 | do | | 0 | 10 | 20 | | | | 100 | | | | | | | | | | | |
| Early 1926 | do | | | | 90 | 100 | | | | | | | | | | | | | | |
| Late 1926 | do | | | | 0 | 50 | 70 | 80 | 100 | | | | | | | | | | | |
| Early 1927 | do | | | | 10 | | | 10 | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | 0 | 20 | | | 30 | 100 | | | | | | | | | | |
| Early 1925 | Immature | | | 0 | | | | 50 | | 70 | | | | 100 | | | | | | |
| Late 1925 | do | | | 0 | | | | 0 | | 0 | | | 20 | | 40 | | | 100 | | |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | 0 | 20 | 40 | 80 | 90 | 90 | 100 | | |
| Late 1927 | do | | | | | 0 | | 30 | | | 100 | | | | | | | | | |
| Early 1925 | Mature | 50 | 60 | 60 | | 100 | | | | | | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 60 | | | 100 | | | | | | | | | | | |
| Early 1926 | do | | | | 100 | | | | | | | | | | | | | | | |
| Late 1926 | do | | | | 0 | 70 | 100 | | | | | | | | | | | | | |
| Early 1927 | do | | | 20 | 40 | | 40 | | 100 | | | | | | | | | | | |
| Late 1927 | do | | | | 40 | 70 | 50 | 100 | | | | | | | | | | | | |
| Early 1925 | Immature | | | 0 | | | | 70 | | 80 | | 90 | | 100 | | | | | | |
| Late 1925 | do | | | 0 | | | | 0 | | 10 | | | 25 | | 100 | | | | | |
| Late 1926 | do | | | | | | 0 | 0 | | 0 | 30 | 40 | 60 | 90 | 90 | 100 | | | | |
| Late 1927 | do | | | | 0 | 0 | 0 | 40 | | 80 | 100 | | | | | | | | | |
| Early 1925 | Mature | 60 | 20 | 60 | | 100 | | | | | | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | 75 | 100 | | | | | | | | | | | | | |
| Early 1926 | do | | | | 100 | | | | | | | | | | | | | | | |
| Late 1926 | do | | | | 0 | 90 | 100 | | | | | | | | | | | | | |
| Early 1927 | do | | | 0 | 10 | 100 | | | | | | | | | | | | | | |
| Late 1927 | do | | | | 100 | | | | | | | | | | | | | | | |
| Early 1925 | Immature | | | 10 | | | | 60 | | 80 | | 100 | | | | | | | | |
| Late 1925 | do | | | 0 | | | | 0 | | 20 | | 75 | | | 100 | | | | | |
| Late 1926 | do | | | | | 0 | | | 10 | | 30 | | 70 | 100 | | | | | | |
| Late 1927 | do | | | | | 0 | 0 | 80 | 100 | | | | | | | | | | | |

TABLE 1.—*Percentage of tubers from early and late-planted and mature and immature dug crops, showing sprouts after 2 weeks in the sprouting room (70° F.) following increasing periods in storage at different temperatures*—Continued

GREEN MOUNTAIN

| When planted | Degree of maturity when dug | Storage temperature | Sprouting after 2 weeks at 70° F. plus number of weeks in storage | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | ° F. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. |
| Early 1926 | Mature | 36 | | | 0 | 40 | 40 | 50 | 70 | | 80 | 80 | 100 | | | | | | |
| Late 1926 | do | | | | 0 | 0 | 0 | 0 | 0 | | 10 | 0 | 90 | 100 | | | | | |
| Early 1927 | do | | | | | | 0 | 0 | 0 | 80 | 80 | 100 | | | | | | | |
| Late 1927 | do | | | | 0 | | 0 | | 0 | | 0 | 0 | 50 | 50 | 100 | | | | |
| Late 1926 | Immature | | | | | 0 | | 0 | | 0 | | 0 | | 0 | 10 | | 10 | | 100 |
| Late 1927 | do | | | | | 0 | | 0 | | 0 | | 0 | | 30 | | 60 | 100 | | |
| Early 1925 | Mature | 40 | 0 | | 25 | 0 | | 80 | | 100 | | | | | | | | | |
| Late 1925 | do | | | | | | | | | 0 | | 0 | 0 | | | | | | |
| Early 1926 | do | | | | 20 | 20 | 30 | 70 | 80 | | 90 | 100 | | | | | | | |
| Late 1926 | do | | | | 0 | 0 | 10 | 30 | 40 | 50 | 70 | 80 | 100 | | | | | | |
| Early 1927 | do | | | | | 0 | 0 | 0 | 40 | 70 | 80 | 100 | | | | | | | |
| Late 1927 | do | | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 40 | 40 | 100 | | | | | |
| Early 1925 | Immature | | | 0 | | | | 20 | | 20 | | 100 | | | | | | | |
| Late 1925 | do | | | 0 | | | | 0 | | 0 | | | 0 | | | | 0 | | 0 |
| Late 1926 | do | | | | | 0 | | 0 | | 0 | | 10 | | 10 | | 20 | 70 | 90 | 100 |
| Late 1927 | do | | | | | 0 | | 0 | | 0 | | 0 | | 40 | | 60 | 80 | 100 | |
| Early 1925 | Mature | 50 | | 10 | | 50 | 100 | | | | | | | | | | | | |
| Late 1925 | do | | | 0 | | 0 | | 0 | | | | | 60 | 100 | | | | | |
| Early 1926 | do | | | | 10 | 40 | | 40 | 60 | | 100 | | | | | | | | |
| Late 1926 | do | | | | 0 | 0 | | 10 | 30 | 40 | 50 | 80 | 100 | | | | | | |
| Early 1927 | do | | | | | 0 | 0 | 0 | 20 | 70 | 70 | 100 | | | | | | | |
| Late 1927 | do | | | | | 0 | 0 | 0 | 10 | | 90 | 100 | | | | | | | |
| Early 1925 | Immature | | | 0 | | | | 30 | | 30 | | | | 50 | | 100 | | | |
| Late 1925 | do | | | 0 | | | | 0 | | 0 | | | 0 | | 50 | | 60 | 100 | |
| Late 1926 | do | | | 0 | | 0 | | 0 | | 0 | | | 10 | | 10 | 20 | | 90 | 100 |
| Late 1927 | do | | | | | | | 0 | | 0 | | | 0 | | | 90 | 100 | | |
| Early 1925 | Mature | 60 | | | | | | | | | | | | | | | | | |
| Late 1925 | do | | | | | | 0 | | 0 | | 25 | | 80 | | 100 | | | | |
| Early 1926 | do | | | | 30 | 50 | 70 | 70 | 90 | | 100 | | | | | | | | |
| Late 1926 | do | | 0 | 0 | 0 | 0 | 20 | 20 | 30 | 50 | 90 | 90 | 100 | | | | | | |
| Early 1927 | do | | | | | 0 | 0 | 0 | 30 | 100 | | | | | | | | | |
| Late 1927 | do | | | | | 0 | 0 | 20 | | 90 | 100 | | | | | | | | |
| Early 1925 | Immature | | | 40 | | | | 20 | | 30 | | | | 100 | | | | | |
| Late 1925 | do | | | | | | | 0 | | 0 | | 0 | | 0 | 60 | 100 | | | |
| Late 1926 | do | | | | | | | | | | | | 10 | 10 | | 40 | 90 | 100 | |
| Late 1927 | do | | | | | | | | | | | 10 | 20 | | | | 100 | | |

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## RUSSET RURAL

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early 1926 | Mature | 36 | | | 0 | 0 | 40 | | 60 | | 80 | 100 | | | | | | | |
| Late 1926 | do | | | | 0 | 0 | 0 | 10 | 0 | 20 | 100 | | | | | | | | |
| Early 1927 | do | | | | | 0 | 0 | 0 | 10 | 50 | | 100 | | | | | | | |
| Late 1927 | do | | | | | | 0 | 0 | 20 | | | 30 | 100 | | | | | | |
| Late 1926 | Immature | | | | | | | | | | | 10 | 10 | 20 | 20 | 20 | | 90 | 100 |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 40 | | 0 | 65 | 100 | | | | | | | | | | | | | |
| Late 1925 | do | | | | | 0 | | | 0 | | 40 | | | | | 100 | | | |
| Early 1926 | do | | | 0 | 0 | 20 | 30 | 40 | | | 100 | | | | | | | | |
| Late 1926 | do | | | 0 | | 0 | | 0 | | | 60 | 60 | 100 | | | | | | |
| Early 1927 | do | | | | | 0 | 0 | 0 | 0 | | | 100 | | | | | | | |
| Late 1927 | do | | | 0 | | 0 | | 0 | | | 0 | 10 | 80 | 100 | | | | | |
| Early 1925 | Immature | | | | | | 80 | | 80 | | | | | 100 | | | | | |
| Late 1925 | do | | | | | | 10 | | 10 | | | | 50 | | 60 | | 75 | 100 | |
| Late 1926 | do | | | | | | 0 | | 0 | | | | 0 | | 30 | 60 | 60 | 100 | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 50 | 0 | 0 | | 90 | 100 | | | | | | | | | | | | |
| Late 1925 | do | | 0 | 0 | | | 0 | | 10 | | 50 | | 100 | | | | | | |
| Early 1926 | do | | | | 0 | | 30 | 30 | 30 | | 90 | | 100 | | | | | | |
| Late 1926 | do | | | 0 | | | 0 | 0 | | 40 | 100 | | | | | | | | |
| Early 1927 | do | | | | | | 0 | 0 | 0 | 0 | | | | | | | | | |
| Late 1927 | do | | | | | | | 0 | 0 | 0 | 0 | 60 | 80 | 100 | | | | | |
| Early 1925 | Immature | | | | | | 30 | | 80 | | | 90 | | 100 | | | | | |
| Late 1925 | do | | | | | | 0 | | 0 | | | | 25 | | 100 | | | | |
| Late 1926 | do | | | | | | | | | | 0 | | 0 | | 30 | 100 | | | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 60 | 0 | 25 | | 60 | | 100 | | | | | | | | | | | |
| Late 1925 | do | | | 0 | | 0 | | | 50 | | 100 | | | | | | | | |
| Early 1926 | do | | | | 0 | 0 | 20 | 40 | 60 | | 100 | | | | | | | | |
| Late 1926 | do | | | 0 | 0 | 0 | | 0 | 50 | 80 | 100 | | | | | | | | |
| Early 1927 | do | | | | | | | 0 | 0 | 0 | | | | | | 100 | | | |
| Late 1927 | do | | | | | | | | 0 | 0 | 0 | 80 | 100 | | | | | | |
| Early 1925 | Immature | | | | 0 | | 0 | | 100 | | | | | | | | | | |
| Late 1925 | do | | | | | | | | | 0 | | | | | 40 | 100 | | | |
| Late 1926 | do | | | | | | | | | | | | | 0 | 40 | | | 100 | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |

The data are condensed and summarized in table 2 so as to show the average time that elapsed before 100 percent germination in 2 weeks in the sprouting room was produced in successive samplings of mature and immature potatoes which had been held previously at temperatures ranging from 36° to 60° F. The rest periods of potatoes held continuously at 70° are shown for comparison. In the case of the Irish Cobbler and Triumph varieties the data are incomplete because of injury [5] resulting from immediate storing of newly harvested potatoes at a temperature of 36°. Many tubers became so badly injured at this temperature that they were discarded. Those transferred from the 36° room were selected for freedom from apparent cold injury; those from the rooms held at other temperatures were taken at random.

During the first 2 years of this work lots of potatoes were similarly stored at 32°, but low-temperature injury showing itself in the killing of the eyes and other symptoms rendered the results useless so far as this study is concerned.

TABLE 2.—*Average length of rest periods of potatoes held at various storage temperatures, as indicated by the time required for 100 percent sprouting to occur after they had been held 2 weeks in the sprouting room (70° F.); also the rest period of potatoes held continuously at 70°*

| Variety | Crop | Maturity of crop when dug | Rest period after storage at temperature of— | | | | Rest period when held continuously at 70° F.[1] |
|---|---|---|---|---|---|---|---|
| | | | 36° F. | 40° F. | 50° F. | 60° F. | |
| | | | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* |
| Irish Cobbler | Early | Mature | [2] 12 | 11.7 | 11.7 | 10.3 | 9.3 |
| | Late | do | 16 | 15.0 | 13.7 | 9.7 | 8.0 |
| | Early | Immature | ---- | 16.0 | 14.0 | 14.0 | 12.0 |
| | Late | do | 16.0 | 17.0 | 16.7 | 13.3 | 10.7 |
| Triumph | Early | Mature | [2] 11.0 | 11.0 | 10.7 | 10.0 | 10.0 |
| | Late | do | 13.5 | 15.0 | 11.7 | 9.3 | 9.0 |
| | Early | Immature | ([2]) | 15.0 | 14.0 | 14.0 | 10.0 |
| | Late | do | 14.0 | 17.0 | 14.3 | 13.0 | 13.5 |
| Early Rose | Early | Mature | 7.5 | 7.0 | 7.0 | 7.3 | 6.0 |
| | Late | do | 11.0 | 10.7 | 8.3 | 5.3 | 6.7 |
| | Early | Immature | ---- | 12.0 | 10.0 | 12.0 | 10.0 |
| | Late | do | 14.0 | 14.7 | 13.7 | 12.7 | 10.7 |
| Spaulding Rose | Early | Mature | 8.5 | 6.7 | 6.7 | 5.7 | 4.3 |
| | Late | do | 12.0 | 9.3 | 8.0 | 6.3 | 6.0 |
| | Early | Immature | ---- | 14.0 | 14.0 | 12.0 | 8.0 |
| | Late | do | 16.5 | 15.7 | 14.0 | 12.7 | 12.3 |
| Green Mountain | Early | Mature | 12.5 | 11.3 | 10.0 | 10.5 | 8.0 |
| | Late | do | 14.5 | 13.5 | 14.0 | 13.0 | 8.5 |
| | Early | Immature | ---- | 12.0 | 16.0 | 14.0 | 10.0 |
| | Late | do | 18.0 | 18.5 | 18.5 | 17.0 | 11.7 |
| Russet Rural | Early | Mature | 11.5 | 9.7 | 10.0 | 11.0 | 9.0 |
| | Late | do | 12.0 | 14.0 | 12.7 | 11.7 | 10.0 |
| | Early | Immature | ---- | 14.0 | 14.0 | 9.0 | 10.0 |
| | Late | do | 18.0 | 18.0 | 15.5 | 17.0 | 15.7 |

[1] The data presented in this column were obtained from potatoes held continuously at 70° F., with 2 weeks deducted from the time of sprouting in order to present the results on a par with those of potatoes held at the other temperatures.

[2] 1926-crop tubers injured by this storage temperature.

A point of interest brought out in table 2 is the tendency in most instances for potatoes of the early crop, which matures and is har-

[5] This does not refer to freezing injury, as freezing of potato tissue will not take place at 32° F. or above. For a more complete discussion of low-temperature injury see PEACOCK, W. M., and WRIGHT, R. C., LOW TEMPERATURE INJURY TO POTATOES WHEN STORED SHORTLY AFTER HARVEST. Potato Assoc. of America, 13th ann. meeting, Dec. 28–29, 1926. Proceedings pp. 99–101. WRIGHT, R. C., PEACOCK, W. M., THE STORAGE OF POTATOES IMMEDIATELY AFTER HARVEST. Potato Assoc. of America, 14th ann. meeting, Dec. 28–30, 1927. Proceedings pp. 126–130.

vested during the heat of midsummer, to have a shorter rest period than those from the same lot of seed but planted later and matured and harvested in the fall. An exception to this generalization is seen in the instances of Irish Cobbler and Triumph varieties from storage temperatures of 60° and 70° F. where the opposite is shown. Another point of importance is the fact that the rest period of mature potatoes was approximately 1 to 8 weeks shorter than that of immature potatoes.

On account of the dissimilar results obtained from the different varieties and from the early and late crops it is obvious that these must be considered separately in studying the relative influence of the various storage temperatures upon the rest period. It can be said safely, however, that there is a general tendency in all crops toward a shortening of the rest period as the storage temperature increases.

The rest period of the early mature crops of all varieties proved to be influenced less by the different storage temperatures than were the late mature crops, while the early mature crops of the Early Rose and Russet Rural varieties were apparently less affected than were the other varieties. The average rest period of the mature potatoes of the late-planted crops of the Irish Cobbler, Triumph, Early Rose, and Spaulding Rose varieties was 5.5 weeks or 42 percent shorter when stored at 60° F. than when stored at 36° F.; with the Green Mountain and Russet Rural varieties the difference was rather insignificant.

At 40° F., the usual commercial storage temperature, the shortest rest period of the late mature potatoes, which represents the crop usually stored, occurred with the Spaulding Rose variety, which averaged 9.3 weeks for the 3 years. Next in order were the Early Rose, 10.7 weeks; Green Mountain, 13.5 weeks; Russet Rural, 14 weeks; and Irish Cobbler and Triumph varieties, 15 weeks each. In the same test the varieties of the early mature crops arranged in the order of their rest periods were Spaulding Rose, 6.7 weeks; Early Rose, 7 weeks; Russet Rural, 9.7 weeks; Triumph, 11 weeks; Green Mountain, 11.3 weeks; and Irish Cobbler, 11.7 weeks. The rest periods of the immature early and late crops of all varieties held at this temperature averaged slightly over 4 weeks longer than those of the mature potatoes. These data support the results reported by Rosa,[6] who stored both mature and immature lots of the White Rose, Idaho Rural, and Irish Cobbler varieties for an average of 31 days at 73.4° and 33.8° F., after which they were cut into seed pieces and planted in soil. Sprouts from the mature seed potatoes appeared above the ground before those from the immature ones.

### DORMANCY AT DIFFERENT STORAGE TEMPERATURES

While the data were being taken on the sprouting of potatoes transferred to the sprouting room, records were also made of the sprouting as it occurred under continuous storage at the various temperatures. The lowest temperature at which such sprouting was noted was 40° F. Records were kept of potatoes stored at 40°, 50°, 60°, and 70°, and the time when all of the tubers of each lot had

[6] ROSA, J. T. RELATION OF TUBER MATURITY AND OF STORAGE FACTORS TO POTATO DORMANCY. Hilgardia 3: 99–124, illus. 1928.

sprouted at these temperatures is given in table 3. No consistent general difference was observed between the early and late mature crops, but in the immature crops those planted late apparently required a somewhat longer period to sprout than did those planted early. Also, most of the immature tubers when stored required a somewhat longer period to sprout than did the mature ones.

TABLE 3.—*The average dormant period (time when 100 percent show sprouts) of potatoes kept continuously at various storage temperatures*

| Variety | Crop | Maturity when dug | Number of weeks held at— | | | |
|---|---|---|---|---|---|---|
| | | | 40° F. | 50° F. | 60° F. | 70° F. |
| Irish Cobbler | Early | Mature | 25.0 | 18.5 | 10.3 | 11.3 |
| | Late | do | 24.0 | 19.5 | 12.7 | 10.0 |
| | Early | Immature | | 16.0 | 14.0 | 14.0 |
| | Late | do | 26.0 | 20.0 | 17.7 | 12.7 |
| Triumph | Early | Mature | | 18.5 | 15.5 | 12.0 |
| | Late | do | 23.0 | 19.0 | 11.7 | 11.0 |
| | Early | Immature | | | 14.0 | 12.0 |
| | Late | do | 26.0 | 18.5 | 15.7 | 15.5 |
| Early Rose | Early | Mature | 18.0 | 14.5 | 11.5 | 8.0 |
| | Late | do | 15.0 | 13.5 | 11.0 | 8.7 |
| | Early | Immature | | 16.0 | 12.0 | 12.0 |
| | Late | do | 22.0 | 16.3 | 14.7 | 12.7 |
| Spaulding Rose | Early | Mature | 18.0 | 18.0 | 12.5 | 6.3 |
| | Late | do | 20.0 | 14.0 | 9.0 | 8.0 |
| | Early | Immature | | | | 10.0 |
| | Late | do | 21.0 | 17.5 | 13.0 | 14.3 |
| Green Mountain | Early | Mature | 25.0 | 18.0 | 16.0 | 10.0 |
| | Late | do | 27.5 | 15.0 | 14.0 | 10.5 |
| | Early | Immature | | | | 12.0 |
| | Late | do | 26.0 | 20.0 | 17.5 | 13.7 |
| Russet Rural | Early | Mature | | 16.0 | 13.0 | 11.0 |
| | Late | do | 20.0 | 15.3 | 13.3 | 12.0 |
| | Early | Immature | | | | 12.0 |
| | Late | do | | 18.5 | 16.5 | 17.7 |

As might be expected, the varieties studied showed varying germination responses when held at different storage temperatures. For example, at 40° F. storage the mature tubers of different varieties began germinating in an average of 16.5 weeks in the case of the Early Rose variety, whereas the Spaulding Rose variety required 19 to germinate; Russet Rural, 20; Triumph, 23; Irish Cobbler, 24.5; and Green Mountain, 26 weeks. In general, the dormant period shortened as the storage temperature increased. Averaging all varieties, the dormant period at 70° continuous storage was practically half of that at 40°. The immature potatoes in general remained dormant longer than the mature ones. After sprouting had started at each temperature the higher the storage temperature the more rapid the rate of growth. At 40°, after sprouting was evident, the growth of the sprouts was very slow. Even after 2 months the increase in length of sprouts was almost insignificant.

REST PERIODS IN LOTS TRANSFERRED TO THE SPROUTING ROOM AFTER DIFFERENT STORAGE PERIODS AT VARIOUS TEMPERATURES AND LEFT UNTIL SPROUTING FINALLY OCCURRED

In addition to the data already discussed there accumulated certain data from which it was possible to select instances showing the length of rest periods for potatoes moved to the sprouting room and held beyond the usual 2 weeks' period until sprouting finally occurred, after having been held in storage at 36°, 40°, 50°, and 60° F. for increasing periods of time. This information is of scientific interest as well as of practical value when it is desirable to know how soon potatoes germinate following removal from storage for different periods at various temperatures. These data are assembled in table 4 to show the time required for all of the potatoes in a sample to germinate in the sprouting room after increasingly lengthy periods in storage at different temperatures. It is not possible to present this table in the form of a summary because of the irregular transfer periods of the different lots. In general, the various lots were transferred to the sprouting room after 2 to 5 weeks in storage and at fairly short intervals thereafter.

TABLE 4.—*Time required for 100 percent germination of tubers in sprouting room after various preliminary periods in storage at different temperatures*

IRISH COBBLER

| When planted | Degree of maturity when dug | Storage temperature | Average period in sprouting room after being stored for the number of weeks indicated | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | ° F. | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* (1) | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* |
| Early 1926 | Mature | 36 | | | | | | 5 | 5 | 5 | 4 | 3 | 3 | | 3 | | 2 | | | |
| Late 1926 | do | | | | | | 6 | 5 | 5 | 5 | 5 | 4 | 2 | | | | | | | |
| Early 1927 | do | | | | | 5 | 5 | 5 | 5 | 5 | 5 | 4 | 2 | | | | | | | |
| Late 1927 | do | | | | | | | 5 | 4 | 4 | 3 | | 3 | 3 | | | 2 | | | |
| Late 1926 | Immature | | | | | | 8 | 7 | 7 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 2 | | | |
| Late 1927 | do | | | | | 5 | | | 5 | 5 | 5 | 5 | 4 | 4 | 3 | | 2 | | | |
| Early 1925 | Mature | 40 | | | 6 | | | | 6 | | 4 | | 2 | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | 5 | | | 5 | | 4 | | 4 | | 2 | | | | |
| Early 1926 | do | | | | | 6 | | 6 | | | 3 | 2 | | | | | | | | |
| Late 1926 | do | | | | | | | | 5 | 5 | 4 | 4 | 4 | | 3 | 2 | | | | |
| Early 1927 | do | | | | | 5 | 5 | 6 | 5 | 4 | 4 | 4 | 2 | | | | | | | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | | |
| Early 1925 | Immature | | 12 | | 8 | | 8 | | 6 | | 6 | | | | 4 | 3 | 2 | | | |
| Late 1925 | do | | 11 | | 9 | | | | 7 | | 5 | | | 5 | | | | 2 | | |
| Late 1926 | do | | | | | | 7 | 7 | 6 | 6 | 5 | 5 | 4 | 4 | 4 | 3 | | | 2 | |
| Late 1927 | do | | | | | 5 | | | 5 | 5 | 5 | 4 | 3 | 3 | | 3 | 2 | | | |
| Early 1925 | Mature | 50 | | | 6 | | | | 4 | | 2 | | | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | | | | 4 | 4 | 4 | | 2 | | | | | | |
| Early 1926 | do | | | | | 5 | | 5 | | | 4 | 3 | 2 | | | | | | | |
| Late 1926 | do | | | | | | | 5 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | | | | | |
| Early 1927 | do | | | | | 5 | 6 | 6 | 5 | 4 | 4 | 4 | 3 | 2 | | | | | | |
| Late 1927 | do | | | | | | | 6 | 5 | 4 | 3 | 3 | 3 | 3 | 2 | | | | | |
| Early 1925 | Immature | | 12 | | 8 | | 8 | | 6 | | 4 | | | | 2 | | | | | |
| Late 1925 | do | | 11 | | 9 | | | | 7 | | 5 | | | 4 | | 2 | | | | |
| Late 1926 | do | | | | | | 8 | | 7 | | 6 | 5 | 4 | 4 | 4 | 3 | 3 | 3 | 2 | |
| Late 1927 | do | | | | | 6 | | | 5 | 4 | 3 | | | | | 3 | | 2 | | |
| Early 1925 | Mature | 60 | | | 6 | | | | 4 | | 2 | | | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | | | | 2 | | | | | | | | | | |
| Early 1926 | do | | | | | | | 6 | | | 4 | | 3 | 2 | | | | | | |
| Late 1926 | do | | | | | | 6 | 5 | 4 | 4 | 3 | 2 | | | | | | | | |
| Early 1927 | do | | | | | 5 | 4 | 4 | 2 | | | | | | | | | | | |
| Late 1927 | do | | | | | | | 4 | 3 | 2 | | | | | | | | | | |
| Early 1925 | Immature | | 12 | | 8 | | 8 | | 4 | | 4 | | | | 2 | | | | | |
| Late 1925 | do | | 11 | | 9 | | | | 5 | | 5 | | | 4 | 2 | | | | | |
| Late 1926 | do | | | | | | 8 | | 7 | | 6 | 5 | 4 | 4 | 3 | 2 | | | | |
| Late 1927 | do | | | | | 5 | | | 3 | 4 | 3 | 2 | | | | | | | | |

## TRIUMPH

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early 1926 | Mature | 36 | | | | 5 | | 7 | | | 4 | 4 | (1) | | | | | | |
| Late 1926 | do | | | | | | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 3 | 2 | | | | |
| Early 1927 | do | | | | | 4 | 4 | 4 | 4 | 3 | 3 | 2 | 3 | 2 | | | | | |
| Late 1927 | do | | | | | | | 4 | 4 | 4 | 4 | 3 | | | | | | | |
| Late 1926 | Immature | | | | | | 7 | 6 | 6 | 6 | 5 | 4 | 4 | 4 | 4 | (1) | | | |
| Late 1927 | do | | | | | 6 | | | 5 | 5 | 4 | 3 | 3 | 3 | 2 | | | | |
| Early 1925 | Mature | 40 | | | 4 | | | | 4 | | 2 | | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | 5 | | | 5 | | 4 | | 4 | | 2 | | | |
| Early 1926 | do | | | | | 5 | | 5 | | | 4 | | 2 | | | | | | |
| Late 1926 | do | | | | | | 6 | 5 | 5 | 4 | 3 | 3 | 3 | 3 | 2 | | | | |
| Early 1927 | do | | | | | 4 | 5 | 5 | 4 | 3 | 3 | 2 | | | | | | | |
| Late 1927 | do | | | | | | | 4 | 4 | 4 | 4 | 4 | | 3 | 3 | 2 | | | |
| Early 1925 | Immature | | 10 | | 8 | | 6 | | 4 | | 4 | | | | 4 | 2 | | | |
| Late 1925 | do | | 11 | | 9 | | | | 7 | | 7 | | | 6 | | | | | |
| Late 1926 | do | | | | | | 7 | 7 | 6 | 6 | | 6 | 5 | 4 | 4 | 4 | 3 | | 2 |
| Late 1927 | do | | | | | 5 | | | 5 | 5 | 5 | | 4 | | 3 | 3 | 2 | | |
| Early 1925 | Mature | 50 | | | 4 | | | | 4 | | 2 | | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | 5 | | | 4 | | 4 | | 2 | | | | | |
| Early 1926 | do | | | | | 5 | | 6 | | | 3 | 3 | 2 | | | | | | |
| Late 1926 | do | | | | | | 6 | 5 | 5 | 5 | 4 | 3 | 2 | | | | | | |
| Early 1927 | do | | | | | 5 | 4 | 4 | 3 | 3 | 2 | | | | | | | | |
| Late 1927 | do | | | | | | | 4 | 4 | 3 | 2 | | | | | | | | |
| Early 1925 | Immature | | 10 | | 8 | | 6 | | 4 | | 4 | | | | 2 | | | | |
| Late 1925 | do | | | | 11 | | | | | | | | | 6 | | | | 4 | 2 |
| Late 1926 | do | | | | | | | 7 | | 7 | | 6 | 5 | 3 | 2 | | | | |
| Late 1927 | do | | | | | 6 | | | 4 | 4 | 4 | 2 | | | | | | | |
| Early 1925 | Mature | 60 | | | 4 | | | | 4 | | 2 | | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | 5 | | | 2 | | | | | | | | | |
| Early 1926 | do | | | | | 5 | 5 | | | | 4 | 3 | 2 | | | | | | |
| Late 1926 | do | | | | | | 6 | 4 | 3 | 3 | 2 | | | | | | | | |
| Early 1927 | do | | | | | 4 | 4 | 4 | 2 | | | | | | | | | | |
| Late 1927 | do | | | | | | | 3 | 3 | 2 | | | | | | | | | |
| Early 1925 | Immature | | 10 | | 8 | | 6 | | 4 | | 4 | | | | 2 | | | | |
| Late 1925 | do | | | | 11 | | | | 7 | | 5 | | | 5 | 2 | | | | |
| Late 1926 | do | | | | | | | 7 | 7 | | | 5 | 3 | 2 | | | | | |
| Late 1927 | do | | | | | 5 | | | 4 | | 3 | 2 | | | | | | | |

[1] Tubers injured by the storage temperature.

TABLE 4.—*Time required for 100 percent germination of tubers in sprouting room after various preliminary periods in storage at different temperatures*—Continued

EARLY ROSE

| When planted | Degree of maturity when dug | Storage temperature | Average period in sprouting room after being stored for the number of weeks indicated | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | °F. | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks |
| Early 1926 | Mature | 36 | | | | 3 | 3 | 2 | | | | | | | | | | | | |
| Late 1926 | do | | | | | | | 5 | 4 | 3 | | 3 | 2 | | | | | | | |
| Early 1927 | do | | | | 4 | 5 | 4 | 3 | 2 | | | | | | | | | | | |
| Late 1927 | do | | | | | 5 | 3 | 3 | 3 | 3 | 2 | | | | | | | | | |
| Late 1926 | Immature | | | | | | | 5 | | 4 | 4 | 3 | | 3 | 3 | | 2 | | | |
| Late 1927 | do | | | | | 4 | | | 4 | 3 | 3 | 3 | 2 | | | | | | | |
| Early 1925 | Mature | 40 | 6 | | 6 | | 2 | | | | | | | | | | | | | |
| Late 1925 | do | | 7 | | 5 | | 5 | | | 2 | | | | | | | | | | |
| Early 1926 | do | | | | | 5 | 4 | 2 | | | | | | | | | | | | |
| Late 1926 | do | | | | | | 4 | 4 | 3 | 3 | | 3 | 2 | | | | | | | |
| Early 1927 | do | | | | 5 | 5 | 4 | 3 | 2 | | | | | | | | | | | |
| Late 1927 | do | | | | | 3 | 3 | 4 | 3 | | 3 | 2 | | | | | | | | |
| Early 1925 | Immature | | 6 | | 6 | | 6 | | 4 | | 4 | | 2 | | | | | | | |
| Late 1925 | do | | 8 | | 6 | | 6 | | 6 | | 5 | | | 4 | | | 2 | | | |
| Late 1926 | do | | | | | | 6 | 6 | 5 | 4 | 4 | 3 | 3 | | 3 | | 2 | | | |
| Late 1927 | do | | | | | 4 | | | 4 | 3 | 3 | 3 | 2 | | | | | | | |
| Early 1925 | Mature | 50 | 4 | | 4 | | 2 | | | | | | | | | | | | | |
| Late 1925 | do | | 7 | | 5 | | 5 | | | 2 | | | | | | | | | | |
| Early 1926 | do | | | | | 4 | 3 | 2 | | | | | | | | | | | | |
| Late 1926 | do | | | | | 3 | 3 | 3 | 2 | | | | | | | | | | | |
| Early 1927 | do | | | | 3 | 4 | 4 | 3 | 2 | | | | | | | | | | | |
| Late 1927 | do | | | | | 4 | 4 | 4 | 2 | | | | | | | | | | | |
| Early 1925 | Immature | | 8 | | 8 | | 6 | | 4 | | 2 | | | | | | | | | |
| Late 1925 | do | | 11 | | 11 | | | | 7 | | 5 | | | 4 | | 2 | | | | |
| Late 1926 | do | | | | | | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 3 | 2 | | | | |
| Late 1927 | do | | | | | 4 | | | 4 | 4 | 3 | 2 | | | | | | | | |
| Early 1925 | Mature | 60 | 8 | | 4 | | 4 | 2 | | | | | | | | | | | | |
| Late 1925 | do | | 7 | | 5 | 3 | 2 | | | | | | | | | | | | | |
| Early 1926 | do | | | | | 3 | 3 | 2 | | | | | | | | | | | | |
| Late 1926 | do | | | | | 2 | | | | | | | | | | | | | | |
| Early 1927 | do | | | | 5 | 5 | 4 | 3 | 2 | | | | | | | | | | | |
| Late 1927 | do | | | | | 2 | | | | | | | | | | | | | | |
| Early 1925 | Immature | | 8 | | 8 | | 6 | | 4 | | 4 | | 2 | | | | | | | |
| Late 1925 | do | | 8 | | 8 | | | | 7 | | 5 | | 2 | | | | | | | |
| Late 1926 | do | | | | | | | | | 5 | 4 | 3 | 2 | | | | | | | |
| Late 1927 | do | | | | | 4 | | | 3 | 2 | | | | | | | | | | |

## SPAULDING ROSE

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early 1926 | Mature | 36 | | | | 5 | 5 | 4 | 2 | | | | | | | | | | | |
| Late 1926 | do | | | | | 4 | 4 | | 4 | 3 | | | 2 | | | | | | | |
| Early 1927 | do | | | 5 | | 5 | 5 | 3 | | 2 | | | | | | | | | | |
| Late 1927 | do | | | | | 5 | 4 | 4 | 3 | 3 | 3 | 3 | 2 | | | | | | | |
| Late 1926 | Immature | | | | | | 7 | 7 | 6 | 6 | 5 | 6 | 6 | | | 3 | | 3 | 2 | |
| Late 1927 | do | | | | | 5 | | | 4 | 4 | 3 | 3 | | | 3 | 2 | | | | |
| Early 1925 | Mature | 40 | 8 | | 4 | 2 | | | | | | | | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | 5 | | | 2 | | | | | | | | | | |
| Early 1926 | do | | | | | 3 | 2 | | | | | | | | | | | | | |
| Late 1926 | do | | | | | 4 | 3 | 3 | 3 | 2 | | | | | | | | | | |
| Early 1927 | do | | | 5 | | 4 | 4 | 3 | | 2 | | | | | | | | | | |
| Late 1927 | do | | | | | 3 | 3 | 3 | 3 | 3 | 2 | | | | | | | | | |
| Early 1925 | Immature | | | | 4 | | | | 4 | | 4 | | | | 2 | | | | | |
| Late 1925 | do | | 8 | | 8 | | | | 5 | | 5 | | | 4 | | | | | 2 | |
| Late 1926 | do | | | | | | 7 | 7 | 6 | 5 | 5 | 5 | | | 3 | 3 | | | 2 | |
| Late 1927 | do | | | | | 4 | | | 4 | 4 | | 2 | | | | | | | | |
| Early 1925 | Mature | 50 | 4 | | 4 | | 2 | | | | | | | | | | | | | |
| Late 1925 | do | | 9 | | 7 | | 5 | | | 2 | | | | | | | | | | |
| Early 1926 | do | | | | | 2 | | | | | | | | | | | | | | |
| Late 1926 | do | | | | | 3 | 3 | 2 | | | | | | | | | | | | |
| Early 1927 | do | | | 5 | | 5 | 4 | 3 | | 2 | | | | | | | | | | |
| Late 1927 | do | | | | | 5 | 3 | 3 | 2 | | | | | | | | | | | |
| Early 1925 | Immature | | | 8 | | | | | 6 | | 4 | | | | 2 | | | | | |
| Late 1925 | do | | 14 | | 11 | | | | 7 | | 5 | | | 4 | | 2 | | | | |
| Late 1926 | do | | | | | | | | | 7 | 6 | 5 | 5 | 4 | | | 2 | | | |
| Late 1927 | do | | | | | 5 | | | 5 | 4 | 3 | 2 | | | | | | | | |
| Early 1925 | Mature | 60 | 4 | | 4 | | 2 | | | | | | | | | | | | | |
| Late 1925 | do | | | | 7 | | 5 | 2 | | | | | | | | | | | | |
| Early 1926 | do | | | | | 2 | | | | | | | | | | | | | | |
| Late 1926 | do | | | | | 3 | 4 | 2 | | | | | | | | | | | | |
| Early 1927 | do | | | 6 | | 5 | 2 | | | | | | | | | | | | | |
| Late 1927 | do | | | | | 2 | | | | | | | | | | | | | | |
| Early 1925 | Immature | | | 8 | | | | | 4 | | 4 | | | 2 | | | | | | |
| Late 1925 | do | | 13 | | 11 | | | | 7 | | 5 | | | | 4 | 2 | | | | |
| Late 1926 | do | | | | | | 10 | | | | 9 | | | 3 | 2 | | | | | |
| Late 1927 | do | | | | | 4 | | | 3 | 2 | | | | | | | | | | |

TABLE 4.—*Time required for 100 percent germination of tubers in sprouting room after various preliminary periods in storage at different temperatures*—Continued

GREEN MOUNTAIN

| When planted | Degree of maturity when dug | Storage temperature | Average period in sprouting room after being stored for the number of weeks indicated | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | ° F. | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks | Weeks |
| Early 1926 | Mature | 36 | | | | 5 | | | 4 | 3 | | 3 | | 2 | | | | | | |
| Late 1926 | do | | | | | | 5 | | 6 | 4 | 4 | 4 | 3 | | 2 | | | | | |
| Early 1927 | do | | | | 7 | 5 | 4 | 5 | 6 | 4 | 3 | | 2 | | | | | | | |
| Late 1927 | do | | | | | 7 | 5 | 6 | 5 | 5 | 4 | 3 | 3 | | 3 | 2 | | | | |
| Late 1926 | Immature | | | | | | 8 | 8 | 8 | 6 | 6 | 5 | 5 | | 4 | 4 | | | | 2 |
| Late 1927 | do | | | | | 7 | | | 6 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | | 2 | | |
| Early 1925 | Mature | 40 | 10 | | 8 | | 6 | | | | 2 | | | | | | | | | |
| Late 1925 | do | | | | 7 | | 7 | | | 6 | | 4 | | | | | | | | |
| Early 1926 | do | | | | | 4 | | | 4 | 3 | | 3 | 2 | | | | | | | |
| Late 1926 | do | | | | | | 5 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | | | | | | |
| Early 1927 | do | | | | 7 | 5 | 5 | 5 | 5 | 4 | 3 | 3 | 2 | | | | | | | |
| Late 1927 | do | | | | | 6 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 2 | | | | | |
| Early 1925 | Immature | | | | | | | | 6 | | 4 | | 2 | | | | | | | |
| Late 1925 | do | | 13 | | 11 | | | | 7 | | 5 | | | 4 | | | | | | |
| Late 1926 | do | | | | | | 7 | 6 | 6 | 6 | 5 | 5 | 5 | | 4 | 4 | 3 | | | 2 |
| Late 1927 | do | | | | | 6 | | | 5 | 4 | 4 | | 4 | | 3 | 3 | | | | |
| Early 1925 | Mature | 50 | 10 | | 8 | | 6 | 2 | | | | | | | | | | | | |
| Late 1925 | do | | | | 9 | | 7 | | | 6 | | | | | 2 | | | | | |
| Early 1926 | do | | | | | 5 | | 4 | 4 | 4 | | 2 | | | | | | | | |
| Late 1926 | do | | | | | | 4 | 4 | | 4 | | 4 | 3 | 2 | | | | | | |
| Early 1927 | do | | | | 7 | 5 | 5 | 5 | 5 | 4 | 3 | | 2 | | | | | | | |
| Late 1927 | do | | | | | 7 | 7 | 6 | 5 | 5 | | 4 | 2 | | | | | | | |
| Early 1925 | Immature | | | | | | | | 6 | | 6 | | | | | | 2 | | | |
| Late 1925 | do | | 13 | | 11 | | | | 8 | | | | | | | | | | 2 | |
| Late 1926 | do | | | | | | | | 7 | 7 | | 6 | 6 | | 5 | 4 | 3 | 3 | | 2 |
| Late 1927 | do | | | | | 7 | | | 7 | 7 | 6 | 5 | 5 | | 4 | 4 | | 2 | | |
| Early 1925 | Mature | 60 | 10 | | | | | | | | | | | | | | | | | |
| Late 1925 | do | | | | 9 | | 7 | | | 6 | | 4 | | | | 2 | | | | |
| Early 1926 | do | | | | | 5 | 4 | | 4 | 3 | 3 | 2 | | | | | | | | |
| Late 1926 | do | | | | | | 4 | 4 | | 4 | 4 | 3 | 3 | 2 | | | | | | |
| Early 1927 | do | | | | 7 | 6 | 5 | 5 | 5 | 4 | 2 | | | | | | | | | |
| Late 1927 | do | | | | | 7 | 7 | 6 | 6 | 5 | 5 | 2 | | | | | | | | |
| Early 1925 | Immature | | | | | | | | 6 | | 6 | | | | 2 | | | | | |
| Late 1925 | do | | 13 | | 11 | | | | 7 | | | | | | | 2 | | | | |
| Late 1926 | do | | | | | | 8 | | 8 | 8 | | | 6 | | 5 | 4 | 3 | 3 | | 2 |
| Late 1927 | do | | | | | 7 | | | 8 | 8 | 7 | 6 | | 5 | 4 | 3 | | 2 | | |

## RUSSET RURAL

| | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early 1926 | Mature | 36 | | | | | 4 | 5 | 5 | 4 | | 3 | 2 | | | | | | | |
| Late 1926 | do | | | | | | 5 | 5 | 5 | 4 | 3 | 2 | | | | | | | | |
| Early 1927 | do | | | | | | | 6 | 6 | 6 | 5 | 3 | 2 | | | | | | | |
| Late 1927 | do | | | | | | | 6 | 6 | 5 | 4 | 3 | 3 | 2 | | | | | | |
| Late 1926 | Immature | | | | | | 8 | 7 | 6 | 5 | | | 5 | | 3 | 3 | | 3 | 2 | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 40 | 6 | | 6 | | 2 | | | | | | | | | | | | | |
| Late 1925 | do | | | | 7 | | 7 | | | 6 | | 4 | | | | | 2 | | | |
| Early 1926 | do | | | | | 4 | 4 | 4 | 5 | 4 | | 2 | | | | | | | | |
| Late 1926 | do | | | | | | | 6 | | 5 | 4 | | 3 | 2 | | | | | | |
| Early 1927 | do | | | | | | | 6 | 6 | 5 | 5 | | 3 | | | | | | | |
| Late 1927 | do | | | | | | | 7 | 6 | 6 | 5 | 4 | 3 | | 2 | | | | | |
| Early 1925 | Immature | | | 8 | | | | | 4 | | 4 | | | | 2 | | | | | |
| Late 1925 | do | | | 11 | | | | | 7 | | 5 | | | | | | | 2 | | |
| Late 1926 | do | | | | | | 8 | 7 | 7 | 7 | | | 5 | 5 | | 4 | | 2 | | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 50 | 6 | | 6 | | 6 | 2 | | | | | | | | | | | | |
| Late 1925 | do | | | | 9 | | 7 | | | 6 | | 4 | | 2 | | | | | | |
| Early 1926 | do | | | | | | 6 | 5 | 5 | 4 | 3 | | | 2 | | | | | | |
| Late 1926 | do | | | | | | 6 | | 6 | 5 | | 2 | | | | | | | | |
| Early 1927 | do | | | | | | | 10 | | | | | | | 2 | | | | | |
| Late 1927 | do | | | | | | | 8 | 7 | 6 | 5 | 4 | 3 | 3 | 2 | | | | | |
| Early 1925 | Immature | | | 8 | | | | | 4 | | 4 | | | | 2 | | | | | |
| Late 1925 | do | | 13 | | | | | | 7 | | 5 | | | | | 2 | | | | |
| Late 1926 | do | | | | | | 9 | | 8 | 8 | 9 | 8 | 7 | 6 | | 4 | 2 | | | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 60 | 6 | | 6 | | 6 | | 2 | | | | | | | | | | | |
| Late 1925 | do | | | | 9 | | 7 | | | 4 | | 2 | | | | | | | | |
| Early 1926 | do | | | | | 5 | | 5 | 5 | 4 | | 2 | | | | | | | | |
| Late 1926 | do | | | | | | 6 | 6 | 6 | 4 | 3 | 2 | | | | | | | | |
| Early 1927 | do | | | | | | | 10 | 8 | 6 | 6 | | | | 2 | | | | | |
| Late 1927 | do | | | | | | | 8 | 7 | 5 | 4 | 4 | 3 | 2 | | | | | | |
| Early 1925 | Immature | | | 6 | | | | | 4 | | 2 | | | | | | | | | |
| Late 1925 | do | | 13 | | | | | | 7 | | 5 | | | | | | 2 | | | |
| Late 1926 | do | | | | | | | | | | | 8 | 7 | 6 | 5 | 4 | | 2 | | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | | |

TABLE 4.—*Time required for 100 percent germination of tubers in sprouting room after various preliminary periods in storage at different temperatures*—Continued

GREEN MOUNTAIN

| When planted | Degree of maturity when dug | Storage temperature | Average period in sprouting room after being stored for the number of weeks indicated | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| | | ° *F.* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* | *Weeks* |
| Early 1926 | Mature | 36 | | | | 5 | | | 4 | 3 | | 3 | | 2 | | | | | | |
| Late 1926 | do | | | | | | 5 | | 6 | 4 | 4 | 4 | 3 | | 2 | | | | | |
| Early 1927 | do | | | | 7 | 5 | 4 | 5 | 6 | 4 | 3 | | 2 | | | | | | | |
| Late 1927 | do | | | | | 7 | 5 | 6 | 5 | 5 | 4 | 3 | 3 | | 3 | 2 | | | | |
| Late 1926 | Immature | | | | | | 8 | 8 | 8 | 6 | 6 | 5 | 5 | | 4 | 4 | | | | 2 |
| Late 1927 | do | | | | | 7 | | | 6 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | | 2 | | |
| Early 1925 | Mature | 40 | 10 | | 8 | | 6 | | | | 2 | | | | | | | | | |
| Late 1925 | do | | | | 7 | | 7 | | | 6 | | 4 | | | | | | | | |
| Early 1926 | do | | | | | 4 | | | 4 | 3 | | 3 | 2 | | | | | | | |
| Late 1926 | do | | | | | | 5 | 4 | 4 | 4 | 4 | 3 | 3 | 2 | | | | | | |
| Early 1927 | do | | | | 7 | 5 | 5 | 5 | 5 | 4 | 3 | 3 | 2 | | | | | | | |
| Late 1927 | do | | | | | 6 | 5 | 5 | 5 | 4 | 4 | 4 | 3 | 3 | 2 | | | | | |
| Early 1925 | Immature | | | | | | | | 6 | | 4 | | 2 | | | | | | | |
| Late 1925 | do | | 13 | | 11 | | | | 7 | | 5 | | | 4 | | | | | | |
| Late 1926 | do | | | | | | 7 | 6 | 6 | 6 | 5 | 5 | 5 | | 4 | 4 | 3 | | | 2 |
| Late 1927 | do | | | | | 6 | | | 5 | 4 | 4 | | 4 | | 3 | 3 | | | | |
| Early 1925 | Mature | 50 | 10 | | 8 | | 6 | 2 | | | | | | | | | | | | |
| Late 1925 | do | | | | 9 | | 7 | | | 6 | | | | | 2 | | | | | |
| Early 1926 | do | | | | | 5 | | 4 | 4 | 4 | | 2 | | | | | | | | |
| Late 1926 | do | | | | | | 4 | 4 | | 4 | | 4 | 3 | 2 | | | | | | |
| Early 1927 | do | | | | 7 | 5 | 5 | 5 | 5 | 4 | 3 | | 2 | | | | | | | |
| Late 1927 | do | | | | | 7 | 7 | 6 | 5 | 5 | | 4 | 2 | | | | | | | |
| Early 1925 | Immature | | | | | | | | 6 | | 6 | | | | | | 2 | | | |
| Late 1925 | do | | 13 | | 11 | | | | 8 | | | | | | | | | | 2 | |
| Late 1926 | do | | | | | | | | 7 | 7 | | 6 | 6 | | 5 | 4 | 3 | 3 | | 2 |
| Late 1927 | do | | | | | 7 | | | 7 | 7 | 6 | 5 | 5 | | 4 | 4 | | 2 | | |
| Early 1925 | Mature | 60 | 10 | | | | | | | | | | | | | | | | | |
| Late 1925 | do | | | | 9 | | 7 | | | 6 | | 4 | | | | | | | | |
| Early 1926 | do | | | | | 5 | 4 | | 4 | 3 | 3 | 2 | | | | | | | | |
| Late 1926 | do | | | | | | 4 | 4 | | 4 | 4 | 3 | 3 | 2 | | | | | | |
| Early 1927 | do | | | | 7 | 6 | 5 | 5 | 5 | 4 | 2 | | | | | | | | | |
| Late 1927 | do | | | | | 7 | 7 | 6 | 6 | 5 | 5 | 2 | | | | | | | | |
| Early 1925 | Immature | | | | | | | | 6 | | 6 | | | | 2 | | | | | |
| Late 1925 | do | | 13 | | 11 | | | | 7 | | | | | | | 2 | | | | |
| Late 1926 | do | | | | | | 8 | | 8 | 8 | | | 6 | | 5 | 4 | 3 | 3 | | 2 |
| Late 1927 | do | | | | | 7 | | | 8 | 8 | 7 | 6 | | 5 | 4 | 3 | | 2 | | |

## RUSSET RURAL

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Early 1926 | Mature | 36 | | | | | 4 | 5 | 5 | 4 | | 3 | 2 | | | | | | |
| Late 1926 | do | | | | | | 5 | 5 | 5 | 4 | 3 | 2 | | | | | | | |
| Early 1927 | do | | | | | | | 6 | 6 | 6 | 5 | 3 | 2 | | | | | | |
| Late 1927 | do | | | | | | | 6 | 6 | 6 | 5 | 4 | 3 | 3 | 2 | | | | |
| Late 1926 | Immature | | | | | | 8 | 7 | 6 | 5 | | | | 5 | | 3 | 3 | 3 | 2 |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 40 | 6 | | 6 | | 2 | | | | | | | | | | | | |
| Late 1925 | do | | | | 7 | | 7 | | | 6 | | 4 | | | | | 2 | | |
| Early 1926 | do | | | | | 4 | 4 | 4 | 5 | 4 | | 2 | | | | | | | |
| Late 1926 | do | | | | | | | 6 | | 5 | 4 | | 3 | 2 | | | | | |
| Early 1927 | do | | | | | | | 6 | 6 | 5 | 5 | | 2 | | | | | | |
| Late 1927 | do | | | | | | | 7 | 6 | 6 | 5 | 4 | 3 | | | | | | |
| Early 1925 | Immature | | | 8 | | | | | 4 | | 4 | | | | 2 | | | | |
| Late 1925 | do | | | 11 | | | | | 7 | | 5 | | | | | | 2 | | |
| Late 1926 | do | | | | | | 8 | 7 | 7 | 7 | | | 5 | 5 | | 4 | | 2 | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 50 | 6 | | 6 | | 6 | 2 | | | | | | | | | | | |
| Late 1925 | do | | | 9 | | | 7 | | | 6 | | 4 | | 2 | | | | | |
| Early 1926 | do | | | | | | 6 | 5 | 5 | 4 | 3 | | | 2 | | | | | |
| Late 1926 | do | | | | | | 6 | | 6 | 5 | | 2 | | | | | | | |
| Early 1927 | do | | | | | | | 10 | | | | | | | 2 | | | | |
| Late 1927 | do | | | | | | | 8 | 7 | 6 | 5 | 4 | 3 | 3 | 2 | | | | |
| Early 1925 | Immature | | | 8 | | | | | 4 | | 4 | | | | 2 | | | | |
| Late 1925 | do | | 13 | | | | | | 7 | | 5 | | | | | | 2 | | |
| Late 1926 | do | | | | | | 9 | | 8 | 8 | 9 | 8 | 7 | 6 | | 4 | 2 | | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |
| Early 1925 | Mature | 60 | 6 | | 6 | | 6 | | 2 | | | | | | | | | | |
| Late 1925 | do | | | 9 | | | 7 | | | 4 | | 2 | | | | | | | |
| Early 1926 | do | | | | 5 | | | 5 | 5 | 4 | | 2 | | | | | | | |
| Late 1926 | do | | | | | | 6 | 6 | 6 | 4 | 3 | 2 | | | | | | | |
| Early 1927 | do | | | | | | | 10 | 8 | 6 | 6 | | | | 2 | | | | |
| Late 1927 | do | | | | | | | 8 | 7 | 5 | 4 | 4 | 3 | 2 | | | | | |
| Early 1925 | Immature | | | 6 | | | | | 4 | | 2 | | | | | | | | |
| Late 1925 | do | | 13 | | | | | | 7 | | 5 | | | | | | 2 | | |
| Late 1926 | do | | | | | | | | | | | 8 | 7 | 6 | 5 | 4 | | 2 | |
| Late 1927 | do | | | | | | | | | | | | | | | | | | |

It will be noted that the time required for total germination in the sprouting room decreased as the storage period increased. This decrease, however, was not in the same proportion as the increase in the storage period. There was, therefore, an actual increase in the total period considering the time in storage plus that in the sprouting room. This increase, which was more marked at the lower temperatures, continued up to the end of the rest period, or to the time when 100 percent germination had occurred.

## SUMMARY

The rest period in potatoes is the period immediately following their harvest during which they will not sprout even if kept under favorable growing conditions.

The dormant period includes the rest period and may extend over such time as potatoes may be kept at temperatures unfavorable for growth without undergoing physiological break-down.

A study was made of the influence of storage temperatures ranging from 36° to 70° F. on the rest period and the dormant period of six varieties of potatoes grown and stored at the Arlington Experiment Farm, Rosslyn, Va.

In this investigation the duration of the rest period at different storage temperatures was determined by storing potatoes at 36°, 40°, 50°, and 60° F. and recording the time they could be stored at each storage temperature before sample lots of 10 tubers each would germinate 100 percent after 2 weeks in a germinating room held at 70° with a high relative humidity.

The duration of the dormant period of potatoes stored at 40°, 50°, 60°, and 70° F. was determined by recording the time when all the tubers of a given lot germinated.

When stored at 40° F. early-planted potatoes, maturing during the heat of the summer, had a 1 to 6 weeks' shorter rest period than those maturing in early November.

A tendency toward a shortening of the rest period as the storage temperature increased was evident.

The average rest period of the late-maturing potatoes of the Irish Cobbler, Triumph, Early Rose, and the Spaulding Rose varieties was 5.5 weeks shorter when they were stored at 60° F. than when they were stored at 36°. With the Green Mountain and Russet Rural varieties the storage temperature had little influence upon the length of the rest period.

At 40° F. storage the rest periods of the late-maturing crops of the different varieties were determined as follows: Spaulding Rose, 9.3 weeks; Early Rose, 10.7 weeks; Green Mountain, 13.5 weeks; Russet Rural, 14 weeks; Irish Cobbler, 15 weeks; and Triumph, 15 weeks.

The rest period of immature potatoes of all varieties averaged between 1 and 8 weeks longer than that of mature potatoes, whereas the latter were dug, on an average, 2 weeks later than the former. This difference, however, appeared to be greater during the early part of the storage period than later. Furthermore, these differences varied from crop to crop, probably because of growing conditions.

The dormant periods at 40° F. storage of the different varieties of mature potatoes, or the time required for all the tubers of a given lot to sprout, was determined as follows: Early Rose, 16.5 weeks; Spaulding

Rose, 19 weeks; Russet Rural, 20 weeks; Triumph, 23 weeks; Irish Cobbler, 24.5 weeks; and Green Mountain, 26 weeks.

Sample lots of potatoes were transferred after increased periods of storage at different temperatures to the sprouting room (70° F.) and were kept there until all the tubers had sprouted. While the holding period before growth occurred in the sprouting room decreased as the storage time increased, the total storage and holding time usually increased until the end of the rest period. The time required in the sprouting room for 100 percent of the potatoes to germinate remained practically constant, in most cases, during the early part of the storage period, though meanwhile the total length of that period at the various temperatures was increasing. Toward the end of the storage period the time required for germination in the sprouting room decreased rapidly.

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# FLUCTUATIONS IN PRICES OF COTTON FUTURES CONTRACTS

By L. D. Howell, *senior agricultural economist, Division of Cotton Marketing, Bureau of Agricultural Economics* [1]

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## INTRODUCTION

A rule limiting fluctuations of prices of cotton futures contracts in any one day to 3 cents a pound was established by the New York Cotton Exchange on August 27, 1917. The reason given for the action was "to avoid abnormal fluctuations of price caused by conditions created by the European war and injurious speculation incident thereto." [2] Because of unsettled price conditions in 1918, the Secretary of Agriculture recommended that cotton futures exchanges further limit changes in prices of cotton futures contracts by narrowing the range of daily fluctuations to 2 cents a pound. This recommendation was accepted by the cotton exchanges in the United States and put into effect on October 4, 1918, and these limits have been maintained ever since.

The rules limiting fluctuations in prices provide that trades for future delivery in any specified month shall not be made during any one day at prices more than 2 cents per pound above or below the closing bid price of cotton for the same delivery on the preceding business day. Nor shall trades for future delivery in any specified month be made during any day at prices more than 2 cents per pound above the lowest or more than 2 cents per pound below the highest price for that month on that day.[3] This rule does not apply after the 15th of any month to trades for delivery during that month.

The study, the results of which are presented herewith, was made to determine the extent and distribution of actual daily and weekly fluctuations in cotton futures prices.

[1] Credit is due Arthur W. Palmer for general supervision and helpful suggestions, and coworkers for assistance in tabulating the data and in the preparation of the charts.

[2] New York Cotton Exchange. Bylaws and rules * * *, amendment 9, rule 30. Ed. 20, p. 122. 1916.

[3] New Orleans Cotton Exchange. charter, constitution, bylaws, and rules * * *. Futures rules, rule 1–A. 1931.
New York Cotton Exchange. charter, bylaws, and rules * * *. Rule 25. Ed. 25, p. 193–194. 1930.
Chicago Board of Trade. rules and regulations * * *. Cotton rule 542. 1931.

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## METHOD AND SCOPE

For the purpose of the study, a period of 16 years was taken, extending from August 1, 1917, to August 1, 1933. The time covered by this study represents a wide range of conditions, and includes periods of rising and of declining prices, of extremely high and extremely low price levels, of war time and of peace time, and of various degrees of prosperity and depression.

The price data presented are confined to those for New York cotton futures contracts.[4] Observations and data available indicate, however, that fluctuations in prices of cotton futures contracts on the New York, New Orleans, and Chicago exchanges generally move closely in line with each other, and it is believed that the data on fluctuations of cotton prices on the New York Cotton Exchange are fairly typical of those for the other two exchanges.

Prices of contracts for delivery during the nearest active month not in process of maturing[5] were used. For instance, the prices used in July, August, and September were for the contracts for October delivery; in October and November, those for December delivery; in December, those for January delivery; in January and February, those for March delivery; in March and April, those for May delivery; and in May and June, those for July delivery. The daily number of price changes for contracts for delivery during the different active months and other information indicate that the volume of trading in contracts for delivery during the nearest active month not in process of maturing was relatively great as compared with the volume of trading in other months, and it is believed that the fluctuations in the prices used may be considered fairly typical of fluctuations in prices of contracts for delivery in other months.

Fluctuations in prices of contracts during the month of their maturity were also calculated for comparison with those for other months.

The daily ranges in prices of contracts above and below the lowest price of the closing range for the same month on the preceding business day were calculated. The ranges in price fluctuations during the day and during the week were also tabulated and are summarized in the tables and charts presented in this bulletin.

## DAILY FLUCTUATIONS IN PRICES

The data on prices of New York futures contracts for the nearest active month not in process of maturing were summarized for the period 1917–18 to 1932–33, inclusive. The results show that the range in these prices during the day equaled or exceeded 2 cents per pound only 19 times, or about 0.4 percent of the time, during this 16-year period (table 1). A range in prices of 2 cents per pound during the day has been reached only 15 times since limits of 2 cents per pound were established by the exchange on October 4, 1918. Prices of contracts during the day rose 2 or more cents per pound above the closing price on the previous day only 6 times, or about 0.1 percent of the time, during this period (table 2). Prices of contracts during the day fell 2 or more cents per pound below the closing price on the previous day only 6 times, or about 0.1 percent of the time, during this period (table 3).

[4] Data were obtained from daily market reports of the New York Cotton Exchange.

[5] Futures contracts for delivery during a specified month mature during that month and may be discharged by delivering and receiving the cotton any day in that month. Notice of intention to deliver must be given 5 business days before the cotton is delivered.

TABLE 1.—*Distribution by number and percentage of days on which they occurred, of the range in prices [1] of New York cotton futures contracts, by price-level groups, 1917–18 to 1932–33*

| Range during day (points) [2] | Trading days | | Days when the price level [3] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–9 | 298 | 6.3 | 146 | 22.8 | 74 | 11.2 | 64 | 5.6 | 13 | 1.3 | 1 | 0.1 | | | | |
| 10–19 | 1,037 | 21.9 | 288 | 45.1 | 245 | 37.0 | 341 | 29.7 | 136 | 13.6 | 18 | 2.7 | 8 | 2.0 | 1 | 0.4 |
| 20–29 | 963 | 20.3 | 144 | 22.6 | 175 | 26.5 | 328 | 28.5 | 201 | 20.2 | 62 | 9.3 | 39 | 9.9 | 14 | 6.2 |
| 30–39 | 667 | 14.1 | 44 | 6.9 | 86 | 13.0 | 179 | 15.6 | 186 | 18.7 | 99 | 14.9 | 43 | 10.9 | 30 | 13.3 |
| 40–49 | 500 | 10.6 | 12 | 1.9 | 41 | 6.2 | 95 | 8.3 | 154 | 15.4 | 103 | 15.4 | 59 | 14.9 | 36 | 16.0 |
| 50–59 | 329 | 6.9 | 2 | .3 | 14 | 2.0 | 53 | 4.6 | 86 | 8.6 | 76 | 11.4 | 49 | 12.4 | 49 | 21.7 |
| 60–69 | 261 | 5.5 | 1 | .1 | 13 | 2.0 | 32 | 2.8 | 69 | 6.9 | 80 | 12.0 | 44 | 11.1 | 22 | 9.8 |
| 70–79 | 204 | 4.3 | 1 | .1 | 5 | .8 | 20 | 1.7 | 53 | 5.3 | 67 | 10.0 | 34 | 8.6 | 24 | 10.6 |
| 80–89 | 116 | 2.4 | | | 3 | .5 | 13 | 1.1 | 20 | 2.0 | 42 | 6.3 | 26 | 6.6 | 12 | 5.4 |
| 90–99 | 97 | 2.1 | 1 | .1 | 3 | .5 | 5 | .4 | 24 | 2.4 | 31 | 4.6 | 23 | 5.8 | 10 | 4.4 |
| 100–109 | 63 | 1.3 | | | 1 | .1 | 5 | .4 | 12 | 1.2 | 16 | 2.4 | 20 | 5.1 | 9 | 4.0 |
| 110–119 | 59 | 1.2 | | | 1 | .1 | 6 | .5 | 10 | 1.0 | 20 | 3.0 | 16 | 4.0 | 6 | 2.7 |
| 120–129 | 27 | .6 | | | | | 2 | .2 | 8 | .8 | 9 | 1.4 | 5 | 1.3 | 3 | 1.3 |
| 130–139 | 27 | .6 | 1 | .1 | 1 | .1 | | | 3 | .3 | 14 | 2.1 | 8 | 2.0 | | |
| 140–149 | 21 | .4 | | | | | | | 5 | .5 | 9 | 1.4 | 6 | 1.5 | 1 | .4 |
| 150–159 | 18 | .4 | | | | | | | 6 | .6 | 5 | .7 | 5 | 1.3 | 2 | .9 |
| 160–169 | 11 | .2 | | | | | 2 | .2 | 1 | .1 | 3 | .5 | 4 | 1.0 | 1 | .4 |
| 170–179 | 8 | .2 | | | | | 2 | .2 | 2 | .2 | 2 | .3 | 1 | .2 | 1 | .4 |
| 180–189 | 10 | .2 | | | | | | | 2 | .2 | 5 | .7 | | | 3 | 1.3 |
| 190–199 | 4 | .1 | | | | | | | 2 | .2 | 1 | .1 | | | 1 | .4 |
| 200 and above | 19 | .4 | | | | | 2 | .2 | 5 | .5 | 5 | .7 | 6 | 1.4 | 1 | .4 |
| Total | 4,739 | 100.0 | 640 | 100.0 | 662 | 100.0 | 1,149 | 100.0 | 998 | 100.0 | 668 | 100.0 | 396 | 100.0 | 226 | 100.0 |

[1] Prices are for contracts for delivery in the nearest active month not in process of maturing.
[2] 100 points=1 cent.
[3] Price level for this purpose is the closing price per pound on the previous trading day.

TABLE 2.—*Distribution by number and percentage of days on which they occurred, of daily fluctuations in prices [1] of New York cotton futures contracts above the closing price on the previous day, by price-level groups, 1917–18 to 1932–33*

| Range during day (points) [2] | Trading days | | Days when the price level [3] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–9 | 1,872 | 39.5 | 385 | 60.2 | 333 | 50.3 | 499 | 43.5 | 349 | 35.0 | 159 | 23.8 | 96 | 24.3 | 51 | 22.5 |
| 10–19 | 959 | 20.2 | 157 | 24.6 | 177 | 26.7 | 278 | 24.2 | 174 | 17.5 | 89 | 13.4 | 52 | 13.2 | 32 | 14.2 |
| 20–29 | 652 | 13.8 | 63 | 9.8 | 83 | 12.5 | 174 | 15.1 | 157 | 15.7 | 92 | 13.8 | 53 | 13.4 | 30 | 13.3 |
| 30–39 | 384 | 8.1 | 19 | 3.0 | 32 | 4.8 | 83 | 7.2 | 90 | 9.0 | 80 | 12.0 | 43 | 10.9 | 37 | 16.4 |
| 40–49 | 309 | 6.5 | 7 | 1.1 | 19 | 2.9 | 47 | 4.1 | 96 | 9.6 | 75 | 11.2 | 42 | 10.6 | 23 | 10.2 |
| 50–59 | 158 | 3.3 | 5 | .8 | 10 | 1.5 | 26 | 2.3 | 44 | 4.4 | 40 | 6.0 | 18 | 4.6 | 15 | 6.6 |
| 60–69 | 125 | 2.6 | | | 3 | .5 | 14 | 1.2 | 21 | 2.1 | 42 | 6.3 | 29 | 7.3 | 16 | 7.1 |
| 70–79 | 61 | 1.3 | 2 | .3 | | | 4 | .3 | 14 | 1.4 | 17 | 2.5 | 17 | 4.3 | 7 | 3.1 |
| 80–89 | 55 | 1.2 | 1 | .1 | | | 6 | .5 | 14 | 1.4 | 19 | 2.8 | 11 | 2.8 | 4 | 1.8 |
| 90–99 | 41 | .9 | | | 3 | .5 | 2 | .2 | 8 | .8 | 17 | 2.5 | 7 | 1.8 | 4 | 1.8 |
| 100–109 | 44 | .9 | 1 | .1 | 2 | .3 | 4 | .3 | 9 | .9 | 12 | 1.8 | 12 | 3.0 | 4 | 1.8 |
| 110–119 | 8 | .2 | | | | | 1 | .1 | 1 | .1 | 3 | .5 | 2 | .5 | 1 | .4 |
| 120–129 | 6 | .1 | | | | | | | 5 | .5 | 1 | .1 | | | | |
| 130–139 | 20 | .4 | | | | | 1 | .1 | 6 | .6 | 7 | 1.1 | 6 | 1.5 | | |
| 140–149 | 12 | .3 | | | | | 5 | .4 | 1 | .1 | 1 | .1 | 4 | 1.0 | 1 | .4 |
| 150–159 | 7 | .2 | | | | | | | 2 | .2 | 4 | .6 | | | 1 | .4 |
| 160–169 | 2 | (4) | | | | | 2 | .2 | | | | | | | | |
| 170–179 | 8 | .2 | | | | | | | 4 | .4 | 3 | .5 | 1 | .2 | | |
| 180–189 | 6 | .1 | | | | | 1 | .1 | 1 | .1 | 4 | .6 | | | | |
| 190–199 | 4 | .1 | | | | | 1 | .1 | 1 | .1 | 1 | .1 | 1 | .2 | | |
| 200 and above | 6 | .1 | | | | | 1 | .1 | 1 | .1 | 2 | .3 | 2 | .4 | | |
| Total | 4,739 | 100.0 | 640 | 100.0 | 662 | 100.0 | 1,149 | 100.0 | 998 | 100.0 | 668 | 100.0 | 396 | 100.0 | 226 | 100.0 |

[1] Prices are for contracts for delivery in the nearest active month not in process of maturing.
[2] 100 points=1 cent.
[3] Price level for this purpose is the closing price per pound on the previous trading day.
[4] Less than 0.1 percent.

TABLE 3.—*Distribution by number and percentage of days on which they occurred, of daily fluctuations in prices [1] of New York cotton futures contracts below the closing price on the previous day, by price-level groups, 1917–18 to 1932–33*

| Range during day (points) [2] | Trading days | | Days when the price level [3] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–9 | 2,037 | 43.0 | 403 | 63.0 | 342 | 51.7 | 542 | 47.2 | 354 | 35.5 | 217 | 32.5 | 124 | 31.3 | 55 | 24.4 |
| 10–19 | 1,030 | 21.7 | 162 | 25.3 | 172 | 26.0 | 297 | 25.7 | 226 | 22.7 | 98 | 14.7 | 42 | 10.6 | 33 | 14.6 |
| 20–29 | 604 | 12.7 | 54 | 8.4 | 69 | 10.5 | 155 | 13.5 | 156 | 15.6 | 87 | 13.0 | 47 | 11.9 | 36 | 15.9 |
| 30–39 | 325 | 6.9 | 13 | 2.0 | 35 | 5.3 | 68 | 5.9 | 83 | 8.3 | 53 | 7.9 | 43 | 10.8 | 30 | 13.3 |
| 40–49 | 225 | 4.7 | 4 | .6 | 17 | 2.6 | 28 | 2.4 | 59 | 5.9 | 66 | 9.9 | 36 | 9.1 | 15 | 6.7 |
| 50–59 | 156 | 3.3 | 2 | .3 | 14 | 2.1 | 24 | 2.1 | 42 | 4.2 | 33 | 4.9 | 27 | 6.8 | 14 | 6.2 |
| 60–69 | 102 | 2.2 | | | 7 | 1.0 | 11 | 1.0 | 24 | 2.4 | 28 | 4.2 | 17 | 4.3 | 15 | 6.7 |
| 70–79 | 69 | 1.5 | | | 2 | .3 | 11 | 1.0 | 14 | 1.4 | 22 | 3.3 | 15 | 3.8 | 5 | 2.2 |
| 80–89 | 47 | 1.0 | | | 2 | .3 | 7 | .6 | 11 | 1.1 | 14 | 2.1 | 8 | 2.0 | 5 | 2.2 |
| 90–99 | 39 | .8 | | | | | 1 | .1 | 10 | 1.0 | 13 | 2.0 | 9 | 2.3 | 6 | 2.7 |
| 100–109 | 30 | .6 | 1 | .2 | 1 | .1 | 1 | .1 | 7 | .7 | 11 | 1.7 | 6 | 1.5 | 3 | 1.3 |
| 110–119 | 18 | .4 | | | 1 | .1 | 2 | .2 | | | 8 | 1.2 | 7 | 1.8 | | |
| 120–129 | 15 | .3 | | | | | | | 5 | .5 | 3 | .5 | 3 | .8 | 4 | 1.8 |
| 130–139 | 8 | .2 | | | | | | | 2 | .2 | 3 | .5 | 3 | .8 | | |
| 140–149 | 11 | .2 | 1 | .2 | | | | | 1 | .1 | 5 | .7 | 4 | 1.0 | | |
| 150–159 | 5 | .1 | | | | | 2 | .2 | | | 1 | .1 | 1 | .2 | 1 | .4 |
| 160–169 | 5 | .1 | | | | | | | 3 | .3 | 2 | .3 | | | | |
| 170–179 | 3 | .1 | | | | | | | | | | | 2 | .5 | 1 | .4 |
| 180–189 | 2 | (4) | | | | | | | | | 1 | .1 | | | 1 | .4 |
| 190–199 | 2 | (4) | | | | | | | 1 | .1 | 1 | .1 | | | | |
| 200 and above | 6 | .1 | | | | | | | | | 2 | .3 | 2 | .5 | 2 | .8 |
| Total | 4,739 | 100.0 | 640 | 100.0 | 662 | 100.0 | 1,149 | 100.0 | 998 | 100.0 | 668 | 100.0 | 396 | 100.0 | 226 | 100.0 |

[1] Prices are for contracts for delivery in the nearest active month not in process of maturing.
[2] 100 points=1 cent.
[3] Price level for this purpose is the closing price per pound on the previous trading day.
[4] Less than 0.1 percent.

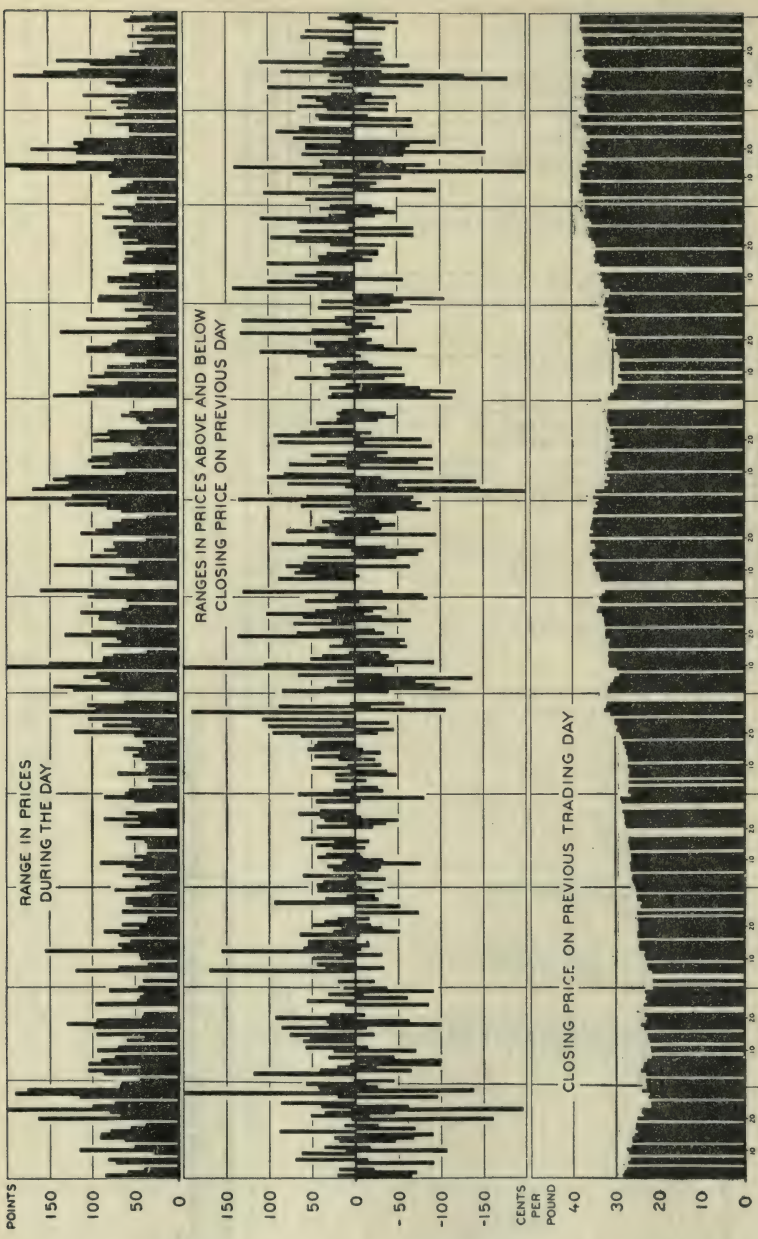


FIGURE 1.—RANGES IN PRICES DURING THE DAY, RANGES IN PRICES ABOVE AND BELOW THE CLOSING PRICES ON THE PREVIOUS TRADING DAY, AND THE CLOSING PRICES ON THE PREVIOUS TRADING DAY, OF NEW YORK COTTON FUTURES CONTRACTS BOUGHT AND SOLD PRIOR TO THE MONTH OF THEIR MATURITY, IN 1919.

The range in prices during the day and also the fluctuations in prices above and below the closing price on the previous day were relatively great when prices were high.

An examination of the data presented in tables 1, 2, and 3 shows that the extent of fluctuations in prices of futures contracts varied directly with the prices[6] of cotton. For example, when cotton prices were below 10 cents per pound, the range in prices during the day amounted to 0.50 cent per pound or more for less than 1 percent of the time; but when prices were 25 to 30 cents per pound, the range

[6] Price used for this purpose is the closing price per pound on the previous trading day.

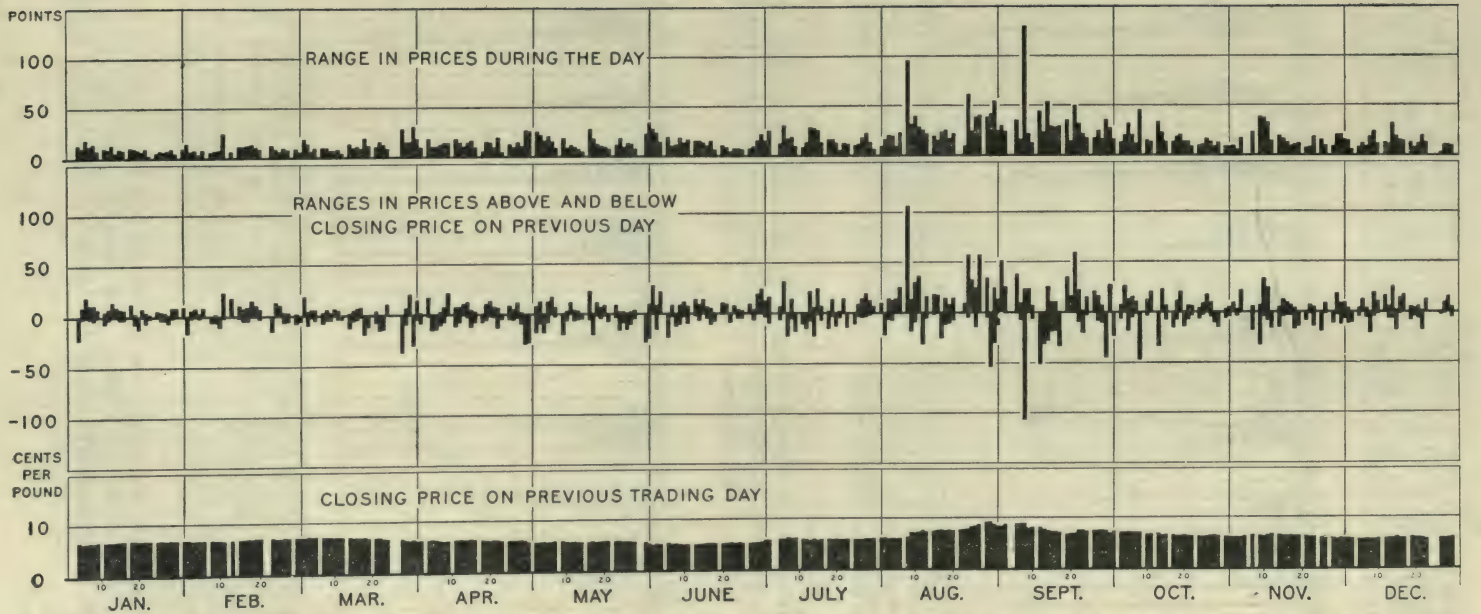


FIGURE 2.—RANGES IN PRICES DURING THE DAY, RANGES IN PRICES ABOVE AND BELOW THE CLOSING PRICES ON THE PREVIOUS TRADING DAY, AND THE CLOSING PRICES ON THE PREVIOUS TRADING DAY, OF NEW YORK COTTON FUTURES CONTRACTS BOUGHT AND SOLD PRIOR TO THE MONTH OF THEIR MATURITY, IN 1932.

The range in prices during the day and fluctuations in prices above and below the closing price on the previous day were relatively narrow when the price level was low.

in prices during the day amounted to 0.50 cent per pound or more about 58 percent of the time. The data presented in figures 1 and 2 show that fluctuations in prices of futures contracts during the day were much greater in 1919, when prices were relatively high, than in

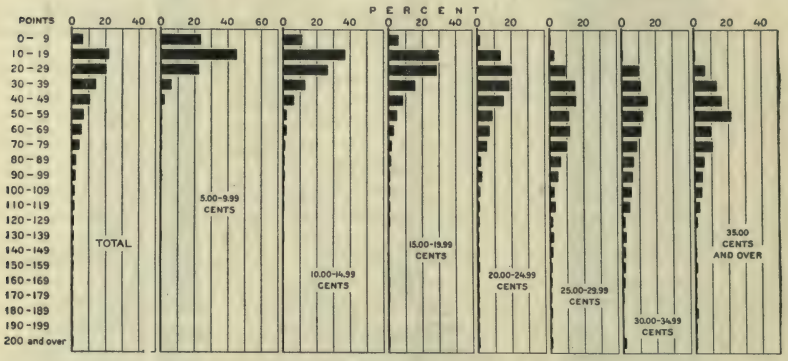


FIGURE 3.—DISTRIBUTION OF DAILY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES, FOR CONTRACTS BOUGHT AND SOLD PRIOR TO THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Daily ranges in cotton futures prices for contracts bought and sold prior to the month of their maturity varied widely, and the proportion of the time these ranges were relatively wide increased considerably from the lower to the higher price-level groups.

1932, when prices were relatively low. This does not mean, however, that the differences in extent of daily fluctuations were due solely to differences in price level, for other conditions in the market may have contributed to these differences. An examination of figures 3 to 5,

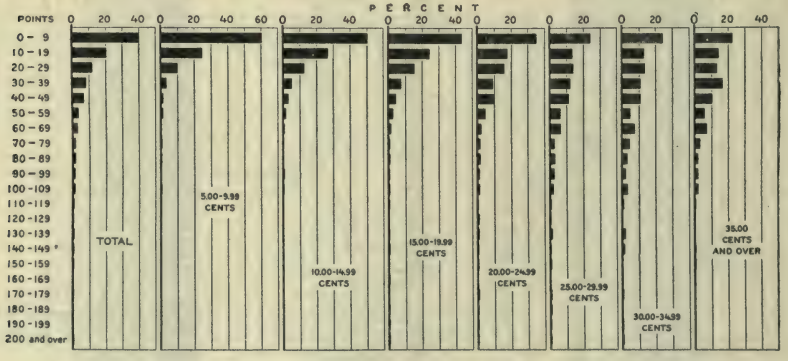


FIGURE 4.—DISTRIBUTION OF DAILY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES ABOVE THE CLOSING PRICE ON THE PREVIOUS BUSINESS DAY, FOR CONTRACTS BOUGHT AND SOLD PRIOR TO THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Daily ranges in cotton futures prices above the closing price on the previous business day, for contracts bought and sold prior to the month of their maturity, varied considerably, and the proportion of the time the ranges were relatively wide increased materially from the lower to the higher price-level groups.

inclusive, shows that the range in prices during the day and the fluctuations in prices above and below the closing price on the previous day increased progressively from the lower to the higher price-level groups.

Data on prices of contracts purchased and sold during the month of their maturity show that the range in prices during the day equaled or exceeded 2 cents per pound only five times, or about 0.3 percent of the time (table 4). These prices rose during the day 2 or more cents

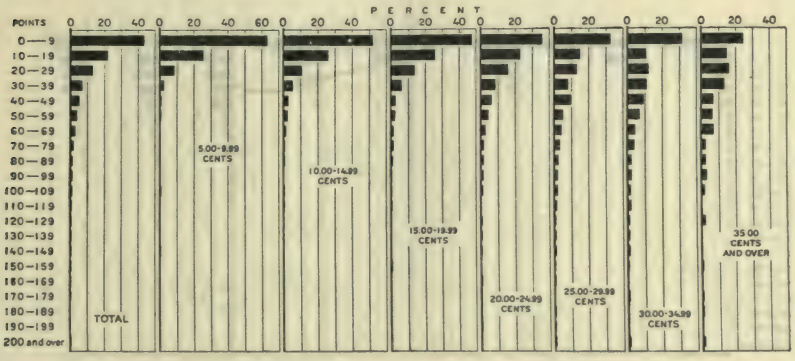


FIGURE 5.—DISTRIBUTION OF DAILY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES BELOW THE CLOSING PRICE ON THE PREVIOUS BUSINESS DAY, FOR CONTRACTS BOUGHT AND SOLD PRIOR TO THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Daily ranges in cotton futures prices below the closing price on the previous business day for contracts bought and sold prior to the month of their maturity varied considerably, and the proportion of the time these ranges were relatively wide increased materially from the lower to the higher price-level group.

per pound above the closing price on the previous day only three times, or about 0.2 percent of the time (table 5), and fell below the closing price on the previous day 2 or more cents per pound only three times, or about 0.2 percent of the time (table 6). These fluctuations

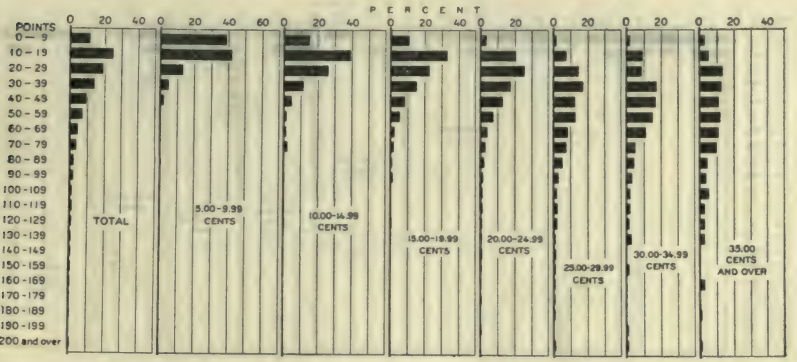


FIGURE 6.—DISTRIBUTION OF DAILY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES, FOR CONTRACTS BOUGHT AND SOLD DURING THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Daily ranges in prices of cotton futures contracts bought and sold during the month of their maturity also varied widely, and the proportion of the time the ranges were relatively wide increased considerably from the lower to the higher price-level groups.

in prices during the day did not equal or exceed 2 cents per pound at any time when cotton prices were below 25 cents per pound.

The data presented in tables 4, 5, and 6 show that the extent of the fluctuations in prices of contracts during the month of their

maturity also varied directly with the level of cotton prices. For example, when cotton prices were below 10 cents per pound, the range in fluctuations in prices during the day did not exceed 0.50 cent per

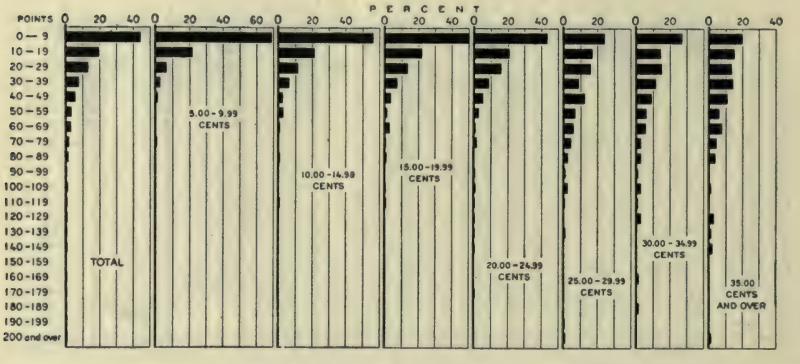


FIGURE 7.—DISTRIBUTION OF DAILY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES ABOVE THE CLOSING PRICE ON THE PREVIOUS BUSINESS DAY, FOR CONTRACTS BOUGHT AND SOLD DURING THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Prices of cotton futures contracts bought and sold during the month of their maturity varied considerably above the closing price on the previous business day, and the proportion of the time these variations were relatively wide increased materially from the lower to the higher price-level groups.

pound at any time during the period 1917–18 to 1932–33, inclusive. When cotton prices were from 25 to 30 cents per pound, however, the range in prices during the day exceeded 0.50 cent per pound about 47

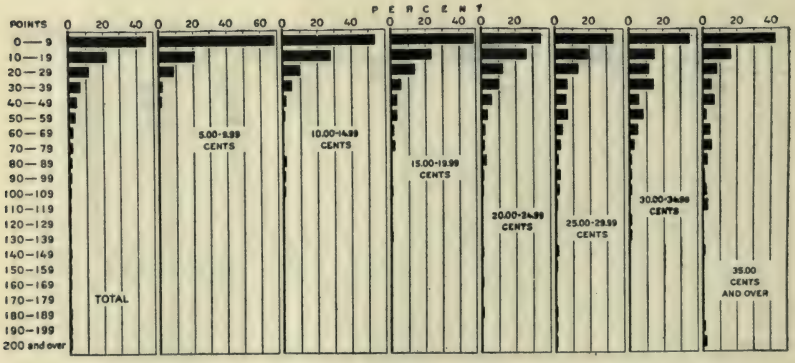


FIGURE 8.—DISTRIBUTION OF DAILY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES BELOW THE CLOSING PRICE ON THE PREVIOUS BUSINESS DAY, FOR CONTRACTS BOUGHT AND SOLD DURING THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Prices of cotton futures contracts bought and sold during the month of their maturity varied considerably below the closing price on the previous business day, and the proportion of the time these variations were relatively wide increased materially from the lower to the higher price-level groups.

percent of the time. The data shown in tables 4, 5, and 6 are presented graphically in figures 6 to 8, inclusive.

TABLE 4.—*Distribution by number and percentage of days on which they occurred, of daily ranges in prices of New York cotton futures contracts, during the month of their maturity, by price-level groups, 1917–18 to 1932–33*

| Range during day (points) [1] | Trading days | | Days when the price level [2] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–9 | 200 | 11.0 | 101 | 38.9 | 37 | 14.7 | 43 | 10.4 | 9 | 2.8 | 4 | 1.4 | 3 | 1.7 | 3 | 2.5 |
| 10–19 | 451 | 24.8 | 109 | 41.9 | 98 | 39.0 | 136 | 33.0 | 65 | 20.3 | 21 | 7.5 | 16 | 9.2 | 6 | 5.0 |
| 20–29 | 346 | 19.0 | 34 | 13.1 | 65 | 25.9 | 93 | 22.6 | 82 | 25.6 | 41 | 14.6 | 15 | 8.6 | 16 | 13.2 |
| 30–39 | 251 | 13.8 | 12 | 4.6 | 28 | 11.2 | 62 | 15.1 | 56 | 17.5 | 48 | 17.2 | 30 | 17.3 | 15 | 12.4 |
| 40–49 | 166 | 9.2 | 4 | 1.5 | 11 | 4.4 | 33 | 8.0 | 41 | 12.8 | 35 | 12.5 | 29 | 16.7 | 13 | 10.7 |
| 50–59 | 123 | 6.8 | | | 3 | 1.2 | 21 | 5.1 | 23 | 7.2 | 36 | 12.9 | 26 | 15.0 | 14 | 11.6 |
| 60–69 | 77 | 4.2 | | | 2 | .8 | 8 | 1.9 | 12 | 3.7 | 23 | 8.2 | 19 | 10.9 | 13 | 10.7 |
| 70–79 | 59 | 3.2 | | | 4 | 1.6 | 6 | 1.5 | 8 | 2.5 | 21 | 7.5 | 8 | 4.6 | 12 | 9.9 |
| 80–89 | 35 | 1.9 | | | | | 3 | .7 | 6 | 1.9 | 14 | 5.0 | 7 | 4.0 | 5 | 4.1 |
| 90–99 | 27 | 1.5 | | | 1 | .4 | 5 | 1.2 | 4 | 1.2 | 8 | 2.9 | 5 | 2.9 | 4 | 3.3 |
| 100–109 | 17 | .9 | | | | | | | 3 | .9 | 5 | 1.8 | 3 | 1.7 | 6 | 5.0 |
| 110–119 | 16 | .9 | | | 1 | .4 | | | 3 | .9 | 6 | 2.1 | 3 | 1.7 | 3 | 2.5 |
| 120–129 | 15 | .8 | | | 1 | .4 | 2 | .5 | 2 | .6 | 5 | 1.8 | 2 | 1.1 | 3 | 2.5 |
| 130–139 | 10 | .6 | | | | | | | 1 | .3 | 2 | .8 | 4 | 2.3 | 3 | 2.5 |
| 140–149 | 5 | .3 | | | | | | | 2 | .6 | 3 | 1.1 | | | | |
| 150–159 | 4 | .2 | | | | | | | 1 | .3 | 1 | .4 | 2 | 1.1 | | |
| 160–169 | 5 | .3 | | | | | | | 1 | .3 | 1 | .4 | | | 3 | 2.5 |
| 170–179 | 2 | .1 | | | | | | | 1 | .3 | 1 | .4 | | | | |
| 180–189 | 2 | .1 | | | | | | | | | 1 | .4 | | | 1 | .8 |
| 190–199 | 2 | .1 | | | | | | | 1 | .3 | | | 1 | .6 | | |
| 200 and above | 5 | .3 | | | | | | | | | 3 | 1.1 | 1 | .6 | 1 | .8 |
| Total | 1,818 | 100.0 | 260 | 100.0 | 251 | 100.0 | 412 | 100.0 | 321 | 100.0 | 279 | 100.0 | 174 | 100.0 | 121 | 100.0 |

[1] 100 points=1 cent.
[2] Price level for this purpose is the closing price per pound on the previous trading day.

TABLE 5.—*Distribution by number and percentage of days when they occurred, of daily fluctuations in prices of New York cotton futures contracts above the closing price on the previous day, during the month of their maturity, by price-level groups, 1917–18 to 1932–33*

| Range during day (points) [1] | Trading days | | Days when the price level [2] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–9 | 802 | 44.1 | 179 | 68.8 | 141 | 56.1 | 205 | 49.8 | 139 | 43.3 | 67 | 24.0 | 47 | 27.0 | 24 | 19.8 |
| 10–19 | 355 | 19.5 | 56 | 21.5 | 53 | 21.1 | 90 | 21.8 | 66 | 20.6 | 47 | 16.8 | 25 | 14.5 | 18 | 14.9 |
| 20–29 | 236 | 13.0 | 16 | 6.2 | 28 | 11.2 | 55 | 13.4 | 51 | 15.9 | 44 | 15.8 | 26 | 14.9 | 16 | 13.2 |
| 30–39 | 138 | 7.6 | 6 | 2.3 | 15 | 6.0 | 29 | 7.0 | 27 | 8.4 | 24 | 8.6 | 20 | 11.5 | 17 | 14.1 |
| 40–49 | 98 | 5.4 | 2 | .8 | 5 | 2.0 | 13 | 3.2 | 16 | 5.0 | 34 | 12.2 | 15 | 8.6 | 13 | 10.8 |
| 50–59 | 53 | 2.9 | | | 6 | 2.4 | 4 | 1.0 | 8 | 2.5 | 18 | 6.5 | 10 | 5.7 | 7 | 5.8 |
| 60–69 | 46 | 2.5 | | | 1 | .4 | 10 | 2.4 | 2 | .6 | 15 | 5.4 | 9 | 5.2 | 9 | 7.4 |
| 70–79 | 26 | 1.4 | 1 | .4 | | | 1 | .2 | 4 | 1.3 | 11 | 3.9 | 4 | 2.3 | 5 | 4.1 |
| 80–89 | 17 | 1.0 | | | 1 | .4 | 2 | .5 | | | 6 | 2.1 | 4 | 2.3 | 4 | 3.3 |
| 90–99 | 4 | .2 | | | | | | | 1 | .3 | 2 | .7 | 1 | .6 | | |
| 100–109 | 13 | .7 | | | | | 1 | .2 | 2 | .6 | 5 | 1.8 | 4 | 2.3 | 1 | .8 |
| 110–119 | 6 | .3 | | | 1 | .4 | 2 | .5 | 1 | .3 | 1 | .4 | 1 | .6 | | |
| 120–129 | 8 | .4 | | | | | | | 1 | .3 | | | 4 | 2.3 | 3 | 2.5 |
| 130–139 | 4 | .2 | | | | | | | 1 | .3 | 2 | .7 | | | 1 | .8 |
| 140–149 | 3 | .2 | | | | | | | 1 | .3 | | | | | 2 | 1.7 |
| 150–159 | | | | | | | | | | | | | | | | |
| 160–169 | 2 | .1 | | | | | | | | | | | 2 | 1.1 | | |
| 170–179 | 1 | .1 | | | | | | | 1 | .3 | | | | | | |
| 180–189 | 2 | .1 | | | | | | | | | | | 2 | 1.1 | | |
| 190–199 | 1 | .1 | | | | | | | | | 1 | .4 | | | | |
| 200 and above | 3 | .2 | | | | | | | | | 2 | .7 | | | 1 | .8 |
| Total | 1,818 | 100.0 | 260 | 100.0 | 251 | 100.0 | 412 | 100.0 | 321 | 100.0 | 279 | 100.0 | 174 | 100.0 | 121 | 100.0 |

[1] 100 points=1 cent.
[2] Price level for this purpose is the closing price per pound on the previous trading day.

TABLE 6.—*Distribution by number and percentage of days when they occurred, of daily fluctuations in prices of New York cotton futures contracts below the closing price on the previous trading day, during the month of their maturity, by price-level groups, 1917–18 to 1932–33*

| Range during day (points) [1] | Trading days | | Days when the price level [2] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–9 | 833 | 45.8 | 178 | 68.5 | 135 | 53.8 | 200 | 48.6 | 112 | 34.9 | 95 | 34.0 | 62 | 35.6 | 51 | 42.1 |
| 10–19 | 406 | 22.3 | 54 | 20.8 | 70 | 27.9 | 97 | 23.5 | 85 | 26.5 | 54 | 19.3 | 26 | 14.9 | 20 | 16.5 |
| 20–29 | 210 | 11.5 | 22 | 8.5 | 25 | 9.9 | 56 | 13.6 | 40 | 12.5 | 37 | 13.2 | 20 | 11.5 | 10 | 8.2 |
| 30–39 | 120 | 6.5 | 4 | 1.5 | 12 | 4.8 | 23 | 5.6 | 32 | 10.0 | 19 | 6.8 | 24 | 13.8 | 6 | 5.0 |
| 40–49 | 72 | 4.0 | 2 | .7 | 3 | 1.2 | 12 | 2.9 | 19 | 5.9 | 17 | 6.0 | 11 | 6.3 | 8 | 6.6 |
| 50–59 | 58 | 3.2 | | | 1 | .4 | 12 | 2.9 | 10 | 3.1 | 19 | 6.8 | 14 | 8.0 | 2 | 1.7 |
| 60–69 | 32 | 1.8 | | | | | 4 | 1.0 | 5 | 1.6 | 10 | 3.6 | 8 | 4.6 | 5 | 4.1 |
| 70–79 | 27 | 1.5 | | | | | 6 | 1.5 | 4 | 1.2 | 7 | 2.5 | 4 | 2.3 | 6 | 5.0 |
| 80–89 | 17 | .9 | | | 3 | 1.2 | | | 7 | 2.2 | 3 | 1.1 | 1 | .6 | 3 | 2.5 |
| 90–99 | 11 | .6 | | | 1 | .4 | | | 2 | .6 | 6 | 2.1 | 1 | .6 | 1 | .8 |
| 100–109 | 10 | .5 | | | 1 | .4 | 1 | .2 | 1 | .3 | 4 | 1.5 | 1 | .6 | 2 | 1.7 |
| 110–119 | 4 | .2 | | | | | | | | | 1 | .4 | | | 3 | 2.5 |
| 120–129 | 1 | .1 | | | | | | | | | | | 1 | .6 | | |
| 130–139 | 2 | .1 | | | | | 1 | .2 | | | | | 1 | .6 | | |
| 140–149 | 5 | .3 | | | | | | | 1 | .3 | 3 | 1.1 | | | 1 | .8 |
| 150–159 | 1 | .1 | | | | | | | | | 1 | .4 | | | | |
| 160–169 | 1 | .1 | | | | | | | 1 | .3 | | | | | | |
| 170–179 | | | | | | | | | | | | | | | | |
| 180–189 | 3 | .2 | | | | | | | 2 | .6 | 1 | .4 | | | | |
| 190–199 | 2 | .1 | | | | | | | | | 1 | .4 | | | 1 | .8 |
| 200 and above | 3 | .2 | | | | | | | | | 1 | .4 | | | 2 | 1.7 |
| Total | 1,818 | 100.0 | 260 | 100.0 | 251 | 100.0 | 412 | 100.0 | 321 | 100.0 | 279 | 100.0 | 174 | 100.0 | 121 | 100.0 |

[1] 100 points=1 cent.
[2] Price level for this purpose is the closing price per pound on the previous trading day.

The limits of 2 cents per pound specified by the rules and regulations of the cotton exchanges were established at a time when the level of cotton futures prices was about 32 cents per pound. When put into effect, these limits represented about 6 percent of the prices of futures contracts. Since then prices of cotton futures contracts have varied from below 5 cents per pound to above 42 cents per pound, and the limits of 2 cents per pound have represented from less than 5 to more than 40 percent of the prices of the contracts. Since the data (tables 1 to 6) showed that fluctuations in prices during the day were greater when cotton prices were relatively high than when they were relatively low, these data were further analyzed (table 7) as a means of indicating roughly whether the changes in level of cotton prices were associated with corresponding proportional changes in daily fluctuations in prices. For this purpose, graduated limits equal to about 6 percent of the prices of contracts were used.

The data presented in table 7 show the number of times and the proportion of the time these graduated limits were exceeded during the period 1917–18 to 1932–33. Some irregularities are noted but, with the exceptions of the extreme price-level groups, the proportion of the time these limits were exceeded did not vary widely from one price-level group to another. This indicates that changes in price level of cotton futures contracts were generally associated with corresponding proportional changes in fluctuations in prices during the day.

TABLE 7.—*Number of times and proportion of the time that the range in prices of New York cotton futures contracts during the day and the fluctuations in these prices above and below the closing price on the previous trading day exceeded specified limits, by price-level groups,[1] 1917–18 to 1932–33*

| Price level [1] (cents per pound) | Graduated limit [2] | Contracts for the nearest active month not in process of maturing | | | | | | | Contracts traded in during the month of their maturity | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Days | Number of times and proportion of time graduated limit was exceeded by— | | | | | | Days | Number of times and proportion of time graduated limit was exceeded by— | | | | | |
| | | | Price range during day | | Decline below close on previous day | | Rise above close on previous day | | | Price range during day | | Decline below close on previous day | | Rise above close on previous day | |
| | *Points* [3] | *Number* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| Below 10 | 50 | 640 | 6 | 0.9 | 4 | 0.6 | 9 | 1.4 | 260 | 0 | 0.0 | 0 | 0.0 | 1 | 0.4 |
| 10–14.99 | 80 | 662 | 9 | 1.4 | 4 | .6 | 5 | .8 | 251 | 3 | 1.2 | 5 | 2.0 | 2 | .8 |
| 15–19.99 | 110 | 1,149 | 14 | 1.2 | 4 | .3 | 12 | 1.0 | 412 | 2 | .5 | 1 | .2 | 2 | .5 |
| 20–24.99 | 140 | 998 | 23 | 2.3 | 5 | .5 | 10 | 1.0 | 321 | 6 | 1.9 | 4 | 1.2 | 2 | .6 |
| 25–29.99 | 170 | 668 | 13 | 1.9 | 4 | .6 | 10 | 1.5 | 279 | 5 | 1.8 | 3 | 1.1 | 3 | 1.1 |
| 30–34.99 | 200 | 396 | 6 | 1.5 | 2 | .5 | 2 | .5 | 174 | 1 | .6 | 0 | .0 | 0 | .0 |
| 35 and above | 230 | 226 | 0 | .0 | 0 | .0 | 0 | .0 | 121 | 0 | .0 | 0 | .0 | 0 | .0 |

[1] Price level for this purpose is the closing price per pound on the previous trading day.
[2] Limit equal to approximately 6 percent of the prices of contracts.
[3] 100 points=1 cent.

FIGURE 9.—CLOSING PRICES ON FRIDAY OF EACH WEEK AND WEEKLY RANGES IN PRICES OF COTTON FUTURES ON THE NEW YORK COTTON EXCHANGE FOR CONTRACTS FOR DELIVERY DURING THE NEAREST ACTIVE MONTH NOT IN PROCESS OF MATURING, 1917–18 TO 1932–33.

Weekly ranges in cotton futures prices varied considerably, but in general these ranges were relatively wide when the price level was relatively high.

The range in fluctuations in prices during the day exceeded the graduated limits 1.5 percent of the time for contracts for delivery during the nearest active month not in process of maturing, and 0.9 percent of the time for contracts traded in during the month of their maturity. The ranges in prices during the day were generally greater than the fluctuations in prices above and below the closing price on the previous day.

## WEEKLY FLUCTUATIONS IN PRICES

The data on weekly fluctuations in cotton futures prices on the New York Cotton Exchange of contracts for delivery during the nearest active months not in process of maturing show a range of 2 or more cents per pound about 15 percent of the time during the period 1917–18 to 1932–33, inclusive (table 8). The range in prices during the week varied directly with the price of cotton, as shown in detail in figure 9. For example, when cotton prices were below 10 cents per

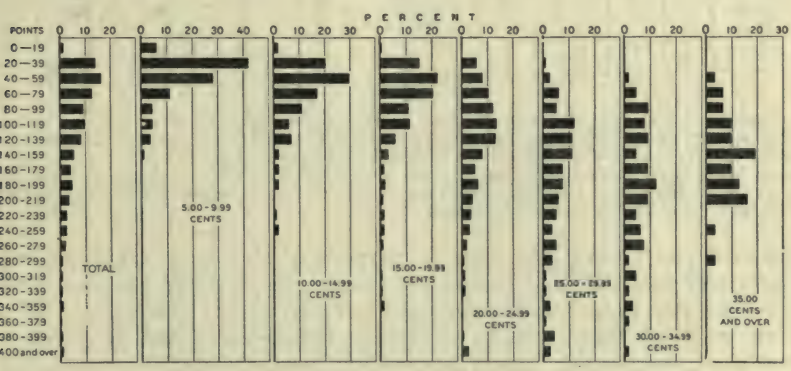


FIGURE 10.—DISTRIBUTION OF WEEKLY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES, FOR CONTRACTS BOUGHT AND SOLD PRIOR TO THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Weekly ranges in cotton futures prices for contracts bought and sold prior to the month of their maturity varied widely, and the proportion of the time the ranges were relatively wide increased considerably from the lower to the higher price-level groups.

pound, the weekly range did not exceed 1.60 cents per pound; whereas, when prices were from 25 to 30 cents per pound, the range exceeded 1.60 cents per pound more than 50 percent of the time. An examination of figure 10 shows that these weekly ranges in prices increased progressively from the lower to the higher price-level groups.

The weekly ranges in prices of cotton futures contracts bought and sold during the month of their maturity were, on the whole, less than those in prices of contracts for other months (table 9). The weekly range in prices of contracts bought or sold during the month of their maturity also varied directly with the price level. When cotton prices were below 10 cents per pound, the weekly range exceeded

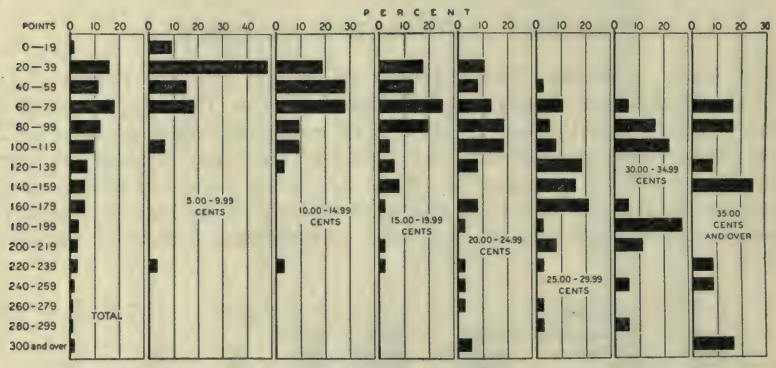


FIGURE 11.—DISTRIBUTION OF WEEKLY RANGES IN PRICES PER POUND OF NEW YORK COTTON FUTURES, FOR CONTRACTS BOUGHT AND SOLD DURING THE MONTH OF THEIR MATURITY, BY PRICE-LEVEL GROUPS, 1917–33.

Weekly ranges in prices of cotton futures contracts bought and sold during the month of their maturity also varied widely and the proportion of the time the ranges were relatively wide increased considerably from the lower to the higher price-level groups.

0.80 cent per pound less than 10 percent of the time; whereas, when prices were from 25 to 30 cents per pound, the weekly range exceeded 0.80 cent per pound approximately 86 percent of the time. Figure 11 shows that these weekly ranges in prices increased progressively from the lower to the higher price-level groups.

TABLE 8.—*Distribution by number and percentage of weeks in which they occurred of the ranges in prices [1] during the week of New York cotton futures contracts, by price-level groups, 1917–18 to 1932–33*

| Range during week (points) [2] | Weeks | | Weeks when the price level [3] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–19 | 10 | 1.2 | 7 | 6.0 | 2 | 1.7 | 1 | 0.5 | | | | | | | | |
| 20–39 | 116 | 14.0 | 49 | 41.9 | 24 | 20.3 | 32 | 15.2 | 10 | 5.7 | 1 | 0.9 | | | | |
| 40–59 | 134 | 16.1 | 33 | 28.2 | 35 | 29.7 | 47 | 22.4 | 14 | 8.0 | 3 | 2.6 | 1 | 1.6 | 1 | 3.2 |
| 60–79 | 106 | 12.7 | 13 | 11.1 | 20 | 17.0 | 43 | 20.5 | 18 | 10.3 | 7 | 6.0 | 3 | 4.6 | 2 | 6.5 |
| 80–99 | 76 | 9.1 | 5 | 4.3 | 13 | 11.0 | 23 | 10.9 | 21 | 12.0 | 6 | 5.2 | 6 | 9.2 | 2 | 6.5 |
| 100–119 | 82 | 9.9 | 5 | 4.3 | 7 | 5.9 | 24 | 11.4 | 24 | 13.7 | 14 | 12.1 | 5 | 7.7 | 3 | 9.7 |
| 120–139 | 69 | 8.3 | 4 | 3.4 | 8 | 6.8 | 12 | 5.7 | 23 | 13.1 | 13 | 11.2 | 6 | 9.2 | 3 | 9.7 |
| 140–159 | 45 | 5.4 | 1 | .8 | 2 | 1.7 | 6 | 2.9 | 14 | 8.0 | 13 | 11.2 | 3 | 4.6 | 6 | 19.3 |
| 160–179 | 32 | 3.9 | | | 2 | 1.7 | 3 | 1.4 | 9 | 5.1 | 9 | 7.7 | 6 | 9.2 | 3 | 9.7 |
| 180–199 | 38 | 4.6 | | | 2 | 1.7 | 4 | 1.9 | 11 | 6.3 | 9 | 7.7 | 8 | 12.3 | 4 | 12.9 |
| 200–219 | 27 | 3.3 | | | | | 2 | 1.0 | 7 | 4.0 | 7 | 6.0 | 6 | 9.2 | 5 | 16.1 |
| 220–239 | 19 | 2.3 | | | 1 | .8 | 3 | 1.4 | 6 | 3.4 | 6 | 5.2 | 3 | 4.6 | | |
| 240–259 | 19 | 2.3 | | | 2 | 1.7 | 3 | 1.4 | 5 | 2.9 | 4 | 3.4 | 4 | 6.1 | 1 | 3.2 |
| 260–279 | 16 | 1.9 | | | | | 2 | 1.0 | 3 | 1.7 | 6 | 5.2 | 5 | 7.7 | | |
| 280–299 | 7 | .8 | | | | | | | 1 | .6 | 4 | 3.4 | 1 | 1.6 | 1 | 3.2 |
| 300–319 | 7 | .8 | | | | | 1 | .5 | 2 | 1.1 | 1 | .9 | 3 | 4.6 | | |
| 320–339 | 5 | .6 | | | | | 1 | .5 | 2 | 1.1 | 1 | .9 | 1 | 1.6 | | |
| 340–359 | 8 | 1.0 | | | | | 3 | 1.4 | | | 3 | 2.6 | 2 | 3.0 | | |
| 360–379 | 2 | .2 | | | | | | | | | 1 | .9 | 1 | 1.6 | | |
| 380–399 | 6 | .7 | | | | | | | 1 | .6 | 5 | 4.3 | | | | |
| 400 and above | 8 | .9 | | | | | | | 4 | 2.4 | 3 | 2.6 | 1 | 1.6 | | |
| Total | 832 | 100.0 | 117 | 100.0 | 118 | 100.0 | 210 | 100.0 | 175 | 100.0 | 116 | 100.0 | 65 | 100.0 | 31 | 100.0 |

[1] Prices are for contracts for delivery in the nearest active month not in process of maturing.
[2] 100 points=1 cent.
[3] Price level for this purpose is the closing price per pound for the week.

TABLE 9.—*Distribution by number and percentage of weeks in which they occurred of the ranges in prices during the week of New York cotton futures contracts, during the month of their maturity, by price-level groups, 1917–18 to 1932–33*

| Range during week (points) [1] | Trading days | | Weeks when the price level [2] was— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Below 10 cents | | 10 to 14.99 cents | | 15 to 19.99 cents | | 20 to 24.99 cents | | 25 to 29.99 cents | | 30 to 34.99 cents | | 35 cents and above | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 0–19 | 3 | 1.4 | 3 | 9.1 | | | | | | | | | | | | |
| 20–39 | 35 | 15.8 | 16 | 48.5 | 6 | 18.8 | 9 | 17.6 | 4 | 10.5 | | | | | | |
| 40–59 | 25 | 11.3 | 5 | 15.1 | 9 | 28.1 | 7 | 13.7 | 3 | 7.9 | 1 | 2.6 | | | | |
| 60–79 | 40 | 18.0 | 6 | 18.2 | 9 | 28.1 | 13 | 25.5 | 5 | 13.2 | 4 | 10.6 | 1 | 5.6 | 2 | 16.7 |
| 80–99 | 27 | 12.2 | | | 3 | 9.4 | 10 | 19.6 | 7 | 18.5 | 2 | 5.3 | 3 | 16.6 | 2 | 16.7 |
| 100–119 | 21 | 9.5 | 2 | 6.1 | 3 | 9.4 | 2 | 3.9 | 7 | 18.5 | 3 | 7.9 | 4 | 22.2 | | |
| 120–139 | 15 | 6.8 | | | 1 | 3.1 | 3 | 5.9 | 3 | 7.9 | 7 | 18.4 | | | 1 | 8.3 |
| 140–159 | 13 | 5.8 | | | | | 4 | 7.8 | | | 6 | 15.8 | | | 3 | 25.0 |
| 160–179 | 13 | 5.8 | | | | | 1 | 2.0 | 3 | 7.9 | 8 | 21.1 | 1 | 5.6 | | |
| 180–199 | 7 | 3.2 | | | | | | | 1 | 2.6 | 1 | 2.6 | 5 | 27.7 | | |
| 200–219 | 6 | 2.7 | | | | | 1 | 2.0 | | | 3 | 7.9 | 2 | 11.1 | | |
| 220–239 | 6 | 2.7 | 1 | 3.0 | 1 | 3.1 | 1 | 2.0 | 1 | 2.6 | 1 | 2.6 | | | 1 | 8.3 |
| 240–259 | 3 | 1.4 | | | | | | | 1 | 2.6 | | | 1 | 5.6 | 1 | 8.3 |
| 260–279 | 2 | .9 | | | | | | | 1 | 2.6 | 1 | 2.6 | | | | |
| 280–299 | 2 | .9 | | | | | | | | | 1 | 2.6 | 1 | 5.6 | | |
| 300 and above | 4 | 1.6 | | | | | | | 2 | 5.2 | | | | | 2 | 16.7 |
| Total | 222 | 100.0 | 33 | 100.0 | 32 | 100.0 | 51 | 100.0 | 38 | 100.0 | 38 | 100.0 | 18 | 100.0 | 12 | 100.0 |

[1] 100 points=1 cent.
[2] Price level for this purpose is the closing price per pound for the week.

Further analyses of the data in tables 8 and 9 were made by applying graduated limits equal to approximately 10 percent of the prices of futures contracts as a means of indicating whether changes in the level of cotton prices were associated with corresponding proportional changes in the ranges in price fluctuations during the week. The data in table 10 show the number of times and proportion of the time that these graduated limits were exceeded during the period 1917–18 to 1932–33. The weekly range in prices exceeded these limits 10.8 percent of the time for contracts bought and sold prior to the month of their maturity and 4.6 percent of the time for contracts bought and sold during the month of their maturity. The proportion of the time that these limits were exceeded varied somewhat from one price-level group to another; but the data indicate that, on the whole, changes in price level were associated with corresponding changes in weekly fluctuations in prices.

TABLE 10.—*Number of times and proportion of the time that weekly range in prices of cotton futures contracts on the New York Cotton Exchange exceeded specified graduated limits, by price-level groups,*[1] *1917–18 to 1932–33*

| Price level (cents per pound) | Contracts not in month of their maturity | | | | Contracts in month of their maturity | | | |
|---|---|---|---|---|---|---|---|---|
| | Weeks | Graduated limit [2] | Limit exceeded | | Weeks | Graduated limit [2] | Limit exceeded | |
| | | | Times | Proportion of time | | | Times | Proportion of time |
| | *Number* | *Points* | *Number* | *Percent* | *Number* | *Points* | *Number* | *Percent* |
| Below 10 | 117 | 80 | 15 | 12.8 | 33 | 80 | 3 | 9.1 |
| 10–14.99 | 118 | 130 | 13 | 11.0 | 32 | 130 | 1 | 3.1 |
| 15–19.99 | 210 | 180 | 19 | 9.0 | 51 | 180 | 2 | 3.9 |
| 20–24.99 | 175 | 230 | 21 | 12.0 | 38 | 230 | 4 | 7.9 |
| 25–29.99 | 116 | 280 | 18 | 15.5 | 38 | 280 | 1 | 3.0 |
| 30–34.99 | 65 | 330 | 4 | 6.2 | 18 | 330 | 0 | -------- |
| 35 and above | 31 | 380 | 0 | -------- | 12 | 380 | 0 | -------- |

[1] Price level for this purpose is the closing price per pound for the week.
[2] Limits equal to approximately 10 percent of the prices of contracts.

## SUMMARY

The results of this study of fluctuations in prices of cotton futures contracts show that, for contracts bought and sold prior to the month of their maturity, the range in prices during the day equaled or exceeded 2 cents per pound only 19 times, or about 0.4 percent of the time, during the 16-year period 1917–18 to 1932–33. Fluctuations in prices above and also below the closing price on the previous day each exceeded 2 cents per pound only 6 times, or approximately 0.1 percent of the time.

Changes in prices during the day were less, on the whole, for contracts bought and sold during the month of their maturity than for contracts of other months.

The extent of price changes during the day varied directly with the level of prices of the contracts. The range of prices during the day and fluctuations in prices above and below the closing price on the previous day increased progressively from the lower to the higher price-level groups.

Analyses of the data on the basis of graduated limits indicate that changes in the price level of cotton futures contracts were generally associated with corresponding proportional changes in prices during the day and during the week.

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UNITED STATES DEPARTMENT OF AGRICULTURE

WASHINGTON, D.C.

# FIELD STUDIES ON RESISTANCE OF HYBRID SELECTIONS OF OATS TO COVERED AND LOOSE SMUTS

By T. R. STANTON, *senior agronomist*, F. A. COFFMAN, *associate agronomist*, and V. F. TAPKE, *pathologist, Division of Cereal Crops and Diseases, Bureau of Plant Industry* [1]

(The Bureau of Plant Industry in cooperation with the Iowa, North Dakota, Montana, Idaho, and Oregon Agricultural Experiment Stations)

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## INTRODUCTION

Smuts take an estimated toll of approximately 45,000,000 bushels of oats annually.[2] The formaldehyde seed treatment, long recommended for the control of oat smuts, is effective, yet the annual loss of oats caused by smuts continues to be heavy. This indicates that, in general, seed treatment is not commonly practiced. Another method of reducing oat losses is by breeding and developing smut-resistant varieties.

[1] The writers express their appreciation to L. C. Burnett, chief in cereal breeding, Iowa Agricultural Experiment Station, and agent, Division of Cereal Crops and Diseases, Bureau of Plant Industry, U.S. Department of Agriculture, for assistance in conducting experiments at Ames, and to the following members of the Division of Cereal Crops and Diseases for assistance in conducting field experiments: R. W. Smith, associate agronomist, at Dickinson, N.Dak.; B. B. Bayles, associate agronomist, formerly at Moccasin, Mont., and Moro, Oreg.; G. A. Wiebe, assistant agronomist, formerly at Aberdeen, Idaho; and D. E. Stephens, senior agronomist, at Moro, Oreg.

[2] Estimates based on the following:

UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF PLANT INDUSTRY. ESTIMATES OF CROP LOSSES DUE TO PLANT DISEASES. 1917. U.S.Dept.Agr., Bur. Plant Indus. Plant Disease Bull. 2, no. 1, 18 pp. 1918.

——— CROP LOSSES FROM PLANT DISEASES. 1918. U.S.Dept.Agr., Bur. Plant Indus. Plant Disease Bull. Sup. 6, pp. 186–213. 1919.

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Some of the most important commercial oat varieties in the United States are highly susceptible to covered smut (*Ustilago levis* (Kell. and Sw.) Magn.), or loose smut *U. avenae* (Pers.) Jens., or both. Markton, however, is an exception. The object of the studies reported herein has been to combine, through hybridization and selection, the near smut immunity of Markton with the desirable agronomic characters of some of the susceptible varieties. The tests were conducted for one or more years at stations in the arid, semiarid, and humid sections of the country, affording an opportunity to test the resistance of the selections under a wide range of environmental conditions. In the tests reported herein, the inoculum, in the form of chlamydospores of the loose and covered smut fungi of oats, was applied to seed from which the hulls had been removed. This method, as shown by Stanton et al. (*13*),[3] tends materially to increase smut infection in susceptible oats. Some promising selections were obtained which have both the smut resistance of Markton and the special value of the susceptible parent.

## REVIEW OF LITERATURE

Reed (*3*) was the first to publish extensive data on the resistance of species and varieties of *Avena* to both covered and loose smuts. Later Reed, Griffiths, and Briggs (*9*) reported studies on varietal resistance and susceptibility of oats to covered and loose smuts. In general, similar results were obtained from the strains and varieties when grown at widely separated stations. Reed and Stanton (*10*) reported that selections from a Fulghum-Swedish Select cross reacted similarly toward both smuts, thus in general agreeing with the results of Reed (*3*) and Reed, Griffiths, and Briggs (*9*). Gaines (*2*) presented data on the resistance of varieties and hybrids of oats to *Ustilago levis*. Of 210 varieties and selections tested for resistance to this smut, 21 proved nearly immune. In the remaining sorts the incidence of smut ranged from a mere trace to nearly 100 percent.

The breeding experiments for smut resistance reported in part in this bulletin were begun mainly on the basis of the results obtained by Reed and Stanton (*10*). More recently Reed (*4,5,7*) and Reed and Stanton (*11*) have shown that there are distinct physiologic races of the oat smuts and that the problem of breeding for smut resistance is more complex than it originally appeared to be. For example, Fulghum is resistant to the physiologic forms of *Ustilago levis* and *U. avenae* from Missouri, but is highly susceptible to *U. avenae*-Fulghum and *U. levis*-Fulghum from the Southeastern States.

## MATERIALS AND METHODS

The materials and methods used in this study have been fully described (*1*, *13*). The number of physiologic forms making up the inoculum of the two smut species used in these experiments is not known. However, since the original collections were from various localities in the Northern States, the common smut forms occurring on the varieties of *Avena sativa* L. grown in these States were undoubtedly represented.

[3] Italic numbers in parentheses refer to Literature Cited, p. 9.

## RESISTANCE OF PARENT VARIETIES

In these experiments the parent varieties were grown from artificially inoculated seed at widely separated stations for one or more years. Their reaction to smut under different environmental conditions was thus obtained.

Data on the resistance to covered and loose smut of nine varieties used as parents of hybrids obtained at five agricultural experiment stations in one or more years from 1925 to 1927, inclusive, are presented in table 1. The total number of plants and the number and percentage of smutted plants are also shown.

TABLE 1.—*Resistance and susceptibility of 9 parent oat varieties to covered and loose smuts when grown for 1 or more years at the agricultural experiment stations listed*

[Plants grown from seed artificially inoculated with hulls removed]

| Location of station | Variety | Year | Plants grown from seed inoculated with— | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Ustilago levis | | | Ustilago avenae | | |
| | | | Total plants | Smutted plants | | Total plants | Smutted plants | |
| | | | *Number* | *Number* | *Percent* | *Number* | *Number* | *Percent* |
| Aberdeen, Idaho | Idamine | 1925 | 158 | 121 | 76.6 | | | |
| Do | do | 1926 | 235 | 158 | 67.2 | | | |
| Do | do | 1927 | 62 | 40 | 64.5 | 63 | 44 | 69.8 |
| Ames, Iowa | do | 1926 | 140 | 88 | 62.9 | | | |
| Aberdeen, Idaho | Victory | 1925 | 151 | 140 | 92.7 | | | |
| Do | do | 1926 | 177 | 136 | 76.8 | | | |
| Do | do | 1927 | 41 | 35 | 85.4 | 30 | 30 | 100.0 |
| Ames, Iowa | do | 1926 | 72 | 29 | 40.3 | | | |
| Aberdeen, Idaho | Iogren | 1925 | 43 | 40 | 93.0 | | | |
| Do | do | 1927 | 88 | 85 | 96.6 | 80 | 70 | 87.5 |
| Ames, Iowa | do | 1926 | 41 | 16 | 39.0 | | | |
| Do | do | 1927 | | | | 41 | 19 | 46.3 |
| Moccasin, Mont | do | 1927 | 50 | 39 | 78.0 | | | |
| Aberdeen, Idaho | Silvermine | 1925 | 42 | 15 | 35.7 | | | |
| Do | do | 1927 | 60 | 46 | 76.7 | 58 | 43 | 74.1 |
| Ames, Iowa | do | 1926 | 44 | 21 | 47.7 | | | |
| Dickinson, N.Dak | Swedish Select | 1925 | 103 | 83 | 80.6 | | | |
| Do | do | 1926 | 97 | 72 | 74.2 | | | |
| Do | do | 1927 | 35 | 7 | 20.0 | 37 | 15 | 40.5 |
| Moccasin, Mont | do | 1927 | 79 | 77 | 97.5 | 98 | 89 | 90.8 |
| Moro, Oreg | do | 1926 | 251 | 158 | 62.9 | | | |
| Do | Scottish Chief | 1925 | 114 | 28 | 24.6 | | | |
| Do | do | 1926 | 243 | 31 | 12.8 | | | |
| Moccasin, Mont | do | 1927 | 70 | 0 | 0 | 95 | 47 | 49.5 |
| Moro, Oreg | Early Champion | 1925 | 283 | 280 | 98.9 | | | |
| Do | do | 1926 | 46 | 46 | 100.0 | | | |
| Moccasin, Mont | do | 1927 | 302 | 230 | 76.2 | 378 | 297 | 78.6 |
| Moro, Oreg | Ligowa | 1925 | 15 | 13 | 86.7 | | | |
| Do | do | 1926 | 90 | 71 | 78.9 | | | |
| Moccasin, Mont | do | 1927 | 146 | 138 | 94.5 | 233 | 223 | 95.7 |
| Aberdeen, Idaho | Markton | 1925 | 159 | 0 | 0 | | | |
| Do | do | 1926 | 217 | 0 | 0 | | | |
| Do | do | 1927 | 65 | 0 | 0 | 69 | 0 | 0 |
| Ames, Iowa | do | 1926 | 71 | 0 | 0 | | | |
| Do | do | 1927 | 88 | 0 | 0 | 80 | 0 | 0 |
| Dickinson, N.Dak | do | 1926 | 59 | 0 | 0 | | | |
| Do | do | 1927 | | | | 33 | 0 | 0 |
| Moro, Oreg | do | 1925 | 78 | 0 | 0 | | | |
| Do | do | 1926 | 332 | 0 | 0 | | | |
| Moccasin, Mont | do | 1927 | 123 | 0 | 0 | 150 | 0 | 0 |
| Total or average for Markton. | | | 1,192 | 0 | 0 | 332 | 0 | 0 |

The data in table 1 show that in the *Ustilago levis* series every variety with the exception of Scottish Chief and Markton produced over 50 percent of smutted plants in one or more years. The data for Scot-

tish Chief agree with the results reported by Reed et al. (*9*), both in relatively low infection and in greater susceptibility to *U. avenae* than to *U. levis*. The negative data for Scottish Chief when inoculated with covered smut at Moccasin, Mont., in 1927 are traceable to unfavorable climatic and soil conditions at and immediately following seeding. Markton was consistently free from either smut at all stations in all years. Since these experiments were conducted, Smith and Bressman (*12*) have reported the occurrence of smut in Markton, evidently produced by a hitherto unidentified physiologic form. In general, the parent varieties reacted similarly to both smuts in the one year (1927) in which tests were made.

## RESISTANCE OF SELECTIONS FROM THE UNNAMED OAT C.I. NO. 357

At Aberdeen, Idaho, in 1925, 200 selections from the unnamed oat C.I.[4] no. 357 were grown in head rows and tested for resistance to *Ustilago levis*. The purpose was twofold: To determine the heterogeneity of resistance to smut in this oat from which Markton was selected, and to isolate, if possible, smut-resistant strains superior to Markton. Of the 200 progenies, 112 were entirely free from covered smut. The susceptibility of 88 lines to *U. levis* shows that the original C.I. no. 357, consists of a mixture of strains. Incidentally, it may be noted that this variability in relation to the smut pathogen is paralleled by considerable variation in many minor plant characters.

In order to test further the resistance of the 112 lines, seed from each was sown at Aberdeen, Idaho, and Moro, Oreg., in the spring of 1926. Forty seeds of each line inoculated with spores of *U. levis* were sown at each station. Forty-four of the lines failed to show resistance to covered smut that year. Summary data are presented in table 2. Lines free from smut at both stations are not included in the summary.

TABLE 2.—*Infection in the 44 susceptible progenies of the unnamed oat C.I. no. 357, grown at Aberdeen, Idaho, and Moro, Oreg., in 1926 from seed inoculated with Ustilago levis*

| Location of station | Progenies infected | | Plants grown in infected families | | | Range of infection in progenies | |
|---|---|---|---|---|---|---|---|
| | | | Total | Infected | | Minimum | Maximum |
| | *Number* | *Percent* | *Number* | *Number* | *Percent* | *Percent* | *Percent* |
| Aberdeen, Idaho | 37 | 84.1 | 1,271 | 94 | 7.4 | 2.4 | 35.5 |
| Moro, Oreg | 21 | 47.7 | 489 | 46 | 9.4 | 3.2 | 34.8 |
| Both stations | 14 | 31.8 | 795 | 90 | 11.3 | 2.8 | 34.8 |

The data of table 2 show that 44 of 112 selections which escaped infection at Aberdeen, Idaho, in 1925 were infected in 1926. A range of infection in the different progenies from 2.4 to 35.5 percent at Aberdeen and from 3.2 to 34.8 percent at Moro was obtained. A higher percentage of plants showed smut at Moro than at Aberdeen. The data emphasize the importance of conducting tests for resistance at different stations and in different years. The large number of the original 200 lines that became smutted shows the heterogeneity for smut resistance in the unnamed mass variety C.I. no. 357, from which Markton was selected.

[4] C.I. indicates accession number of the Division of Cereal Crops and Diseases.

It is evident that in the selection of Markton, one of the very best strains of the original mass population, C.I. no. 357, was isolated. The smut-resistant lines resulting from the experiment reported above have been tested for yield at numerous stations, but so far only a few have shown even equality with Markton. Most of them have been decidedly inferior.

## RESISTANCE OF HYBRID SELECTIONS

Numerous hybrid selections have been tested one or more years for resistance to covered smut. The smut-free selections have been further tested for resistance to both covered and loose smuts. In the latter tests lines inoculated with *Ustilago levis* were sown in a series adjacent to the same lines inoculated with *U. avenae*. In several hybrids, remnant $F_2$ seed was tested in $F_3$, furnishing additional results on the reaction of selections to the two smuts.

Experiments were conducted at Aberdeen, Idaho, on the smut reaction of selections from crosses of Iogren × Markton, Silvermine × Markton, Markton × Idamine, and Markton × Victory; at Dickinson, N.Dak., on selections from Markton × Swedish Select; and at Moccasin, Mont., on selections from Markton × Scottish Chief, Markton × Ligowa, Early Champion × Markton, and Markton × Swedish Select. Summarized results are presented in table 3. Data on the smut-free selections are not included.

TABLE 3.—*Percentages of covered and loose smuts in susceptible families of oat hybrids grown in 1927*

| Varieties crossed | Generation | Station | Families tested | Seed inoculum | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Ustilago levis | | | Ustilago avenae | | | Ustilago levis and U. avenae | | |
| | | | | Families infected | Plants infected | Maximum infection | Families infected | Plants infected | Maximum infection | Families infected | Plants infected | Average maximum infection |
| | | | No. | No. | Pct. | Pct. | No. | Pct. | Pct. | No. | Pct. | Pct. |
| Iogren × Markton | $F_3$ | Aberdeen, Idaho | 52 | 35 | 22.0 | 95.7 | 50 | 30.2 | 94.7 | 33 | 30.2 | 92.9 |
| Silvermine × Markton | $F_3$ | do | 45 | 16 | 13.7 | 60.7 | 33 | 12.7 | 52.2 | 14 | 15.3 | 52.0 |
| Markton × Idamine | $F_3$ | do | 45 | 1 | 2.3 | 2.3 | 6 | 10.0 | 30.8 | 1 | 16.6 | 16.6 |
| Markton × Victory | $F_3$ | do | 63 | 1 | 2.5 | 2.5 | 15 | 11.2 | 55.3 | 1 | 12.3 | 12.3 |
| Markton × Swedish Select | $F_3$ | Dickinson, N.Dak. | 102 | 13 | 9.1 | 25.0 | 36 | 21.1 | 85.7 | 8 | 22.4 | 49.1 |
| Markton × Scottish Chief | $F_3$ | Moccasin, Mont. | 44 | 5 | 32.0 | 63.6 | 9 | 17.1 | 45.8 | 5 | 25.8 | 47.9 |
| Do | $F_5$ | do | 96 | 7 | 15.3 | 84.6 | 18 | 21.2 | 94.7 | 4 | 35.4 | 89.7 |
| Markton × Ligowa | $F_3$ | do | 63 | 29 | 19.7 | 54.2 | 43 | 23.7 | 77.3 | 25 | 26.3 | 65.8 |
| Do | $F_5$ | do | 15 | 5 | 12.3 | 33.3 | 6 | 20.1 | 81.8 | 4 | 20.0 | 57.6 |
| Early Champion × Markton | $F_3$ | do | 127 | 60 | 22.1 | 90.0 | 88 | 22.2 | 100.0 | 58 | 26.2 | 86.2 |
| Do | $F_5$ | do | 59 | 15 | 16.0 | 30.8 | 10 | 11.9 | 38.5 | 6 | 17.3 | 27.0 |
| Markton × Swedish Select | $F_4$ | do | 41 | 17 | 30.0 | 81.8 | 18 | 21.0 | 46.7 | 13 | 29.2 | 60.7 |

### IOGREN × MARKTON

An $F_3$ test of the Iogren × Markton cross at Ames, Iowa, for resistance to *Ustilago levis* was low in smut infection and is not reported. In 1927, 52 families were grown from remnant seed of $F_2$ plants at Aberdeen, Idaho. Only 2 remained free from loose smut, 17 being free from covered smut. On a plant-unit basis 30.2 and 22 percent of the plants were infected with *U. avenae* and *U. levis*, respectively.

Of the 33 families infected with both smuts, 30.2 percent of the plants were smutted.

#### SILVERMINE × MARKTON

Remnant seed of 45 of 53 $F_2$ plants of the Silvermine × Markton cross was inoculated with covered and loose smuts and sown at Aberdeen. Smut occurred in 35 of the 45 $F_3$ families. The summary data are shown in table 3. The average number of plants infected was 12.7 percent for loose smut and 13.7 percent for covered smut. Thirty-three of the thirty-five infected families were smutted by *Ustilago avenae* and only 16 by *U. levis*. The two families that showed no loose smut were slightly infected by *U. levis*.

#### MARKTON × IDAMINE

In the Markton × Idamine cross 45 $F_4$ selections not infected with *Ustilago levis* were tested with both loose and covered smuts in the $F_5$. Six families became infected with loose smut and one succumbed to both smuts.

#### MARKTON × VICTORY

Sixty-three $F_5$ selections from previously smut-free families were inoculated with *Ustilago avenae* and *U. levis*. Fifteen of the sixty-three families proved susceptible to loose smut. One family was smutted by both species. These results are similar to those of the Markton × Idamine cross, in that the reaction of a selection to one smut is not an indication of its reaction to the other.

#### MARKTON × SWEDISH SELECT

The incidence of loose and covered smuts in the Markton × Swedish Select cross grown from inoculated seed at Dickinson, N.Dak., in 1927 is summarized in table 3. Forty-one of the one hundred and two $F_3$ families were smutted by *Ustilago avenae* or *U. levis* or both. Loose smut developed in 36 of the families and covered smut in 13. Populations from 41 smut-free $F_3$ families were tested at Moccasin, Mont., for resistance to both *Ustilago avenae* and *U. levis*. Of the 41 $F^4$ families, 19 were free from both smuts, while 22 showed one or the other. Of the 22 $F_4$ families 18 were smutted by *U. avenae* and 17 by *U. levis*. A considerably larger number of families succumbed to *U. levis* at Moccasin than at Dickinson.

The greater susceptibility of the Swedish Select parent to loose smut under the conditions at Dickinson, N.Dak., may explain why so much more loose than covered smut occurred in the $F_3$ hybrid families. However, at Moccasin, Mont., Swedish Select was equally susceptible to both smuts. At Dickinson, certain $F_3$ families showed high susceptibility to loose smut, yet high resistance to covered smut.

#### MARKTON × SCOTTISH CHIEF

Thirty-five of forty-four $F_3$ families grown at Moccasin, Mont., were free from both smuts, 9 were susceptible to loose smut, and 5 to covered smut. A summary of the susceptible families is shown in table 3.

Selections from 96 previously smut-free families were tested at Moccasin in $F_5$ with both *Ustilago avenae* and *U. levis*. Seventy-five families were free from smut. A summary of the 21 families susceptible to one or both smuts is shown in table 3. Suscepts cannot be completely eliminated by testing under field conditions for 1 or 2

years. Even in the $F_5$ 7 of the 96 families that were smut-free the previous year became smutted. In this cross the suscepts to covered smut were almost completely eliminated in $F_3$ and $F_4$.

### MARKTON × LIGOWA

$F_3$ populations were grown at Moccasin from remnant seed of 63 $F_2$ plants that had been tested with *Ustilago levis*. Of the 63 lines, 47 were susceptible to one or the other of the smuts. Summarized data are given in table 3. Of the 47 lines that proved susceptible to one or the other smut, 43 were infected with *U. avenae* and 29 with *U. levis*.

Fifteen of the most promising $F_4$ lines, selected on the basis of freedom from smut and other desirable characters, were further tested with both smuts. Eight were again smut free, but seven proved susceptible to loose or to covered smut. Summarized data are presented in table 3. The occurrence of smut in so large a proportion of these $F_5$ lines shows the difficulty encountered in weeding out the suscepts. Five of the seven lines infected with covered smut were resistant to the causal pathogen in tests in two previous generations.

### EARLY CHAMPION × MARKTON

The resistance to covered smut of selections from the Early Champion × Markton cross was studied at Moro, Oreg., and at Moccasin, Mont. No tests were made with *Ustilago avenae* in Oregon.

At Moccasin 40 seeds of each of 127 $F_2$ plants were inoculated with spores of *U. levis* and a like number of each $F_2$ plant with spores of *U. avenae*. Summarized data are presented in table 3. Of the 127 families grown, 90 succumbed to one or the other of the smuts. A somewhat greater number of families was susceptible to *U. avenae* than to *U. levis*, although the average percentage of plants infected per family is almost identical. Of the 90 families infected with one or the other smut, only 2 were free from loose smut. Twenty-nine families infected with loose smut were free from covered smut.

At Moro 140 $F_3$ progenies of the above cross were grown, of which 103 were smutted. Progenies from each of 3 $F_3$ plants of the 38 smut-free rows in the $F_4$ produced only 3 families that showed covered smut. Of the 101 smut-free $F_4$ families, 59 were tested in the $F_5$ for resistance to both loose and covered smuts at Moccasin, Mont., in 1927. Of the 59 families, 19 were smutted with one or the other or both pathogenes. A summary is presented in table 3.

### DISCUSSION OF RESULTS

The data for hybrid populations inoculated with both loose and covered smuts are of interest in showing the lack of linkage in reaction to the two smuts. These results are somewhat at variance with the conclusions reached by Reed and Stanton (*11*), who found hybrid selections appearing to react in a similar fashion to both smuts. Reed (*6*, *8*) has shown that nearly all the selections from hybrids between Hull-less, a variety highly susceptible to either smut, and Black Mesdag, a variety highly resistant to or nearly immune from both smuts, after retesting certain ones, reacted similarly to the two smuts. The data on selections of Iogren × Markton, Silvermine × Markton, Markton × Swedish Select, Markton × Ligowa, and Early Champion × Markton, reported in this bulletin, do not agree

with those obtained by Reed (*8*). The pistillate parents of these crosses all are highly susceptible to both smuts, yet many selections from their crosses with the highly resistant Markton do not show uniformity in their reaction to the two smuts. Further testing might have shown a similar behavior for some of the apparently dissimilar selections, but since conditions in most of the tests were exceedingly favorable for infection the results seem to be significant.

Average infection percentages for the two smuts in the hybrid selections suggest a slightly greater virulence for the loose smut. This difference is not sufficient, however, to account for the marked dissimilarity in the reaction of some of the selections to the two smuts.

In any effective program of breeding for resistance, the known races of both smuts occurring in a particular region must be used conjointly for satisfactory progress. Furthermore, it is desirable that the selections be tested for smut resistance under several different environments or at different stations. This conclusion is supported by the data on the $F_5$ populations of Markton × Idamine and Markton × Victory crosses shown in table 3. A rather high infection of loose smut was obtained in a few families that showed no infection of covered smut.

## VALUE OF RESISTANT SELECTIONS

As already stated, many of the smut-resistant selections resulting from the studies herein reported are being tested extensively for crop value. There are indications that in some of these selections the smut resistance of Markton has been combined satisfactorily with other desirable characters of the susceptible parents.

Sufficient data are not yet available for definite conclusions relative to these selections, yet so far the highest yielding lines have equalled or slightly exceeded the parent varieties in yield. It is believed that in the end desirable varieties will result that should make possible the commercial growing of smut-free varieties in many sections. New physiologic forms of the smut fungi capable of infecting the present resistant oats might, of course, delay this attainment.

Several of the smut-resistant selections from the unnamed oat C.I. no. 357 have about equaled or slightly exceeded Markton in average yield in the Northern Pacific Coast and Intermountain States. These strains are not adapted in the Corn Belt because of susceptibility to stem and crown rusts.

## SUMMARY AND CONCLUSIONS

The loss of oats from smut approximates 45,000,000 bushels annually. Smut-resistant varieties will help to reduce this loss. The combining of the near-immunity from smut of Markton oats with the other valuable characters of leading commercial varieties is most important.

Crosses of Iogren × Markton, Silvermine × Markton, Markton × Idamine, Markton × Victory, Markton × Swedish Select, Markton × Scottish Chief, Markton × Ligowa, and Early Champion × Markton were grown from seed blackened with smut. The smut spores were applied to seed with the hulls removed. The susceptible hybrids were weeded out in each successive generation. In some cases, however, smutted plants still occurred in the $F_5$.

Promising hybrids have been obtained from the various crosses which combine the near-immunity of Markton with the other desirable characters of the susceptible parent.

Two hundred selections were isolated from the unnamed oat C.I. no. 357, from which Markton originated, and were tested for resistance to covered smut. In the 2 years of the test 156 of the lines became smutted. With this heterogeneity for resistance, considerable variation in morphological characters also occurred. Numerous strains highly resistant to smut, similar to Markton in plant and kernel characters, were among the 200 isolated. The preponderance of selections of this type indicates that Markton probably is representative of the dominant morphological form of the original mass strain. Observations indicated, however, that there was no correlation between the Markton form and smut resistance.

Conditions at the arid (irrigated) and semiarid (dry land) stations in Idaho, North Dakota, Montana, and Oregon were more favorable for the occurrence of smut than were conditions in Iowa.

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# THE EXTERNAL ANATOMY OF THE PARLATORIA DATE SCALE, PARLATORIA BLANCHARDI TARGIONI TOZZETTI, WITH STUDIES OF THE HEAD SKELETON AND ASSOCIATED PARTS

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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# THE EXTERNAL ANATOMY OF THE PARLATORIA DATE SCALE, PARLATORIA BLANCHARDI TARGIONI TOZZETTI, WITH STUDIES OF THE HEAD SKELETON AND ASSOCIATED PARTS [1]

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## INTRODUCTION

Several species of palms found in the date-growing districts of the United States have been shown to be susceptible to the attacks of a scale insect which appears to be the Parlatoria date scale (*Parlatoria blanchardi* Targioni Tozzetti). This species is considered to be the most dangerous insect enemy of the date palm. An indication of the degree to which this insect may infest the fruit and leaves of the date palm is shown in plates 1 and 2. In order to determine whether the scale attacking these palms was actually *Parlatoria blanchardi* and to establish in detail, for all stages, the identity of this species, a thorough study of the external anatomy of the insect has been made.

The palms from which material was secured for use in this study were the date palm (*Phoenix dactylifera* L.), the Canary Island

[1] This work was done in the laboratory of G. F. Ferris at Stanford University, and through his kindness the writer had free access to the Stanford collection of Coccidae, which Professor Ferris has been instrumental in developing into what is probably, next to that in the National Museum at Washington, the best collection of scale insects in the United States. This privilege has proved especially valuable in giving opportunity for comparing the coccid forms collected by the writer on the various species of palms in the date-growing districts of the United States with the different species of *Parlatoria* in the collection. The writer expresses his thanks to Professor Ferris for constant interest and many valuable suggestions. Thanks are also due Dewey C. Moore, of the Government Date Garden at Indio, Calif., for the two photographs of live Parlatoria date-scale infestations, which were taken under field conditions.

palm (*P. canariensis* Hort. ex Chabaud), the Washingtonia palm (*Washingtonia filifera* Wendl.), and the doum palm (*Hyphaene thebaica* Mart.). These are the only palms, or for that matter the only species of plants, upon which the Parlatoria date scale is known to occur in this country. The date palm was imported in an infested condition. The other species have been found free from scale except where the trees were located so near to date palms as to render the source of infestation evident. The Canary Island palm, apparently, is readily attacked. A tree of this species distant 30 or more feet from date palms showed as heavy infestation as the date palms themselves. On the other hand, Washingtonia palms fully as old as the Canary Island palm, which were rubbing branches with old, heavily infested date palms, bore merely a light scattering of scales. The individuals present, however, were completing their life cycles; to what extent the generations finally succumbed and were succeeded by fresh recruits from the date palm, was not determined. The doum palms found infested were 30 feet from the nearest date palm. They were more heavily infested than were the Washingtonia palms but not so heavily attacked as were the Canary Island palms. It is highly probable that the Parlatoria date scale will infest any kind of palm if it can exist as well as it appears to do on such different genera as *Phoenix*, *Washingtonia*, and *Hyphaene*.

The study of every distinguishable external structure of the body in all instars of both sexes was undertaken from individuals collected from each host (except the third and fourth male instars, in which no specimens from Washingtonia palm were used), and included a critical comparison of the corresponding structures on each side of the meson of each individual. The results of this study are fully presented in the text and in illustrations.

No clear evidence was found that the insect from each species of palm was any other than *Parlatoria blanchardi*, and in consequence the description of the condition of each part of the body is based on the specimens studied from all four host palms.

The segmentation of the thorax is based on an interpretation by R. E. Snodgrass, of the Bureau of Entomology, that the spiracles are located on the anterior sections and the legs on the posterior sections of the thoracic segments. The following condition appears to prevail in all stages: On the venter, the prothorax and anterior section of the mesothorax are indistinguishably fused, and are referred to as the "mesoprothorax," the posterior section of the mesothorax and the two sections of the metathorax are distinct, and the first abdominal segment has been crowded out by the caudal migration of the thoracic parts; on the dorsum, the three primary thoracic segments appear to be neither divided nor fused, except in the adult male, and the first abdominal segment has not been obliterated.

In the divided figures, all representing particular individuals (from the date palm if not otherwise specified), the right side represents the dorsal aspect and the left side the ventral aspect; therefore, owing to the variations between the two aspects, the margins do not always precisely correspond. The bars of the pores on these figures, though located beneath the surface, are drawn solid to differ-

Date fruits and thread to which fruits were attached infested with the Parlatoria date scale (*Parlatoria blanchardi* Targioni Tozzetti).

Date leaves infested with the Parlatoria date scale (*Parlatoria blanchardi* Targioni Tozzetti).

entiate the parts clearly. Similar structures shown comparatively on a figure are drawn to the same scale. In the figures no setae or pores have been duplicated along the margins.

The endoskeleton of the head and the associated parts have also been discussed in detail and fully illustrated. The endoskeleton is represented with surface tissue removed in order to indicate its constituents the more clearly.

The terms "dextron" and "sinistron" refer to the right and left sides, respectively, of the insect from a dorsal view. Except where it seemed necessary for clearness to mention the structures on both sides of the body, the general discussion deals only with those of a single side, but in the average measurements and numbers of the parts both sides of the specimens are included, though as separate units, unless otherwise indicated. Words in common use are employed where possible to indicate particular structures or groups of structures; technical terms are used only where they seem necessary and clearly appropriate.

A segment referred to simply by number is the respective abdominal one.

In the discussion of the pores in all stages possessing them, the invaginated tubular type described for the first stage is the type referred to, unless otherwise indicated.

In the original description of (*Aonidia*) *Parlatoria blanchardi*, Targioni Tozzetti (*14*) [2] described for both sexes one more nymphal stage than the writer has observed in his investigations. A study of the structures of the bodies of individuals in process of molting has led to the conclusion that Targioni Tozzetti may have mistaken individuals of different ages of the same stage as representing separate stages, because such individuals appeared to be quite different, owing to growth, change in contour, and increase in sclerotization.

## SYMBOLS USED ON ILLUSTRATIONS

*a*, anus.
*a8ab*, developing eighth abdominal segment of adult.
*1ab–9ab*, first to ninth abdominal segments.
*9abs*, marginal seta of ninth abdominal segment.
*ac*, antecostal suture.
*aca*, anal sclerotic area.
*acx*, precoxal bridge.
*adcla*, developing adult claw.
*adco*, devoloping adult coxa.
*adfe*, developing adult femur.
*adta*, developing adult tarsus.
*adti*, developing adult tibia.
*adtr*, developing adult trochanter.
*alb*, alar buttress.
*alo*, alar lobe.
*amet*, anterior section of metathorax.
*an*, antenna.
*ana*, anterior notal wing acetabulum.
*anp*, anterior notal wing process.
*ap*, anterior marginal plate.
*ar*, anal ridge.
*as*, antennal seta.
*1as–5as*, first to fifth antennal setae.
*ass*, anterior submarginal seta.
*aw*, prealar bridge.
*1ax–4ax*, first to fourth axillary sclerites.
*axc*, axillary cord.
*ba*, base of antenna.
*bb*, basal bar.
*bhs*, border head seta.
*bmn*, base of mandible.
*bmx*, base of maxilla.
*bpen*, base of penis.
*bpl*, base of salivary plunger.
*bs*, basisternum.
*bu*, bulla.
*camr*, caudal membrane articulating against rostrum.
*cart*, caudal rostral thickening.
*cemr*, cephalic membrane articulating against rostrum.
*cert*, cephalic rostral thickening.
*cha*, sclerotic area.
*chs*, caudal head seta.

[2] Italic numbers in parentheses refer to Literature Cited, p. 66.

*cla*, claw.
*cls*, clypeolabral suture.
*co*, coxa.
*cru*, crumena.
*da*, differentiated area.
*db*, distal bar.
*dba*, dorsal band.
*dms*, dorsal marginal seta.
*8dms*, *9dms*, eighth and ninth dorsal marginal setae.
*dor*, dorsal orifice of head skeleton for egress of rostralis.
*dp*, process of dorsal surface.
*dpr*, dorsal prominence at apex of rostrum.
*dw*, developing wing of subsequent stage.
*e*, eye.
*eo*, external opening.
*1ep*, anepisternum.
*2ep*, katepisternum.
*epm*, epimeron.
*et*, external tracheal thickening.
*f*, furca.
*fe*, femur.
*fs*, furcisternum.
*gb*, globular base of spinelike thickening of rostrum.
*gc*, genaceroris.
*gsh*, genital sheath.
*ha*, halteris.
*in*, invagination of alimentary tract.
*ina*, inferarca.
*in9ab*, mouth of invagination of ninth abdominal segment.
*inc*, infercosta.
*inf*, intersegmental furca.
*inl*, line of invagination.
*inm*, invagination of mandibular and maxillary bars.
*inp*, invagination of pharyngeal tube.
*ins*, invagination of mandibular sheath.
*it*, internal tracheal thickening.
*ita*, interarca.
*1l–5l*, first to fifth lobes.
*la*, line of apposition of sides of invaginated tube.
*lap*, lateral apodeme.
*lb*, lateral band.
*le*, leg.
*lmes*, lateral mesal seta.
*lrs*, large rostral seta.
*m*, median vein.
*mab*, marginal bulging.
*mar*, membranous area of scutellum.
*mbp*, mesal body pore.
*mcr*, mouth of crumena.
*mea*, meatus.
*mes*, mesal seta.
*meso*, mesothorax.
*met*, membranous tube.
*meta*, metathorax.
*mhs*, mesal head seta.
*1mhs–3mhs*, first to third mesal head setae.
*mis*, minute invaginated seta.
*mn*, mandible.
*mnb*, mandibular brace.
*mnp*, mandibular pocket.
*mns*, mandibular sheath.
*mnt*, mandibular tendon.
*mof*, mouth of furca.
*mp*, marginal pore.
*mpl*, marginal plate.
*mpr*, maxillary process.
*mrp*, marginal raised pore.
*ms*, marginal seta.
*mx*, maxilla.
*mxb*, maxillary brace.
*mxp*, maxillary pocket.
*mxs*, maxillary sheath.
*mxt*, maxillary tendon.
*o*, internal vaginal opening.
*oe*, esophagus.
*p*, pore.
*pa*, process area of ventral surface.
*p9ab*, developing ninth abdominal segment of fourth stage.
*pbp*, posterior body pore.
*pc*, precosta.
*pcx*, postcoxal bridge.
*pdp*, prominence of dorsal band.
*pe*, peritreme.
*pen*, penis.
*ph*, pharynx.
*phr*, phragma.
*phs*, pharyngeal sclerite.
*pl*, pleural sclerite.
*pla*, pleural acetabulum.
*plc*, pleural wing condyle.
*pls*, porelike structure.
*plw*, pharyngeal lateral wall.
*pmes*, posterior section of mesothorax.
*pmet*, posterior section of metathorax.
*pna*, posterior notal wing acetabulum.
*pnp*, posterior notal wing process.
*po*, pore opening.
*poc*, postcosta.
*pos*, mesothoracic postscutellum.
*pp*, posterior marginal plate.
*pr*, prothorax.
*pra*, third-stage antenna (male).
*prl*, third-stage leg (male).
*prp*, primary pore.
*prs*, suture between head and prothorax.
*ps*, pleural seta.
*psc*, mesothoracic praescutum.
*pss*, posterior submarginal seta.
*ptc*, pharyngeal tube bulblike chamber.
*pte*, pharyngeal tendon.
*ptu*, pharyngeal tube.
*pua*, developing antenna of fourth-stage male.
*puco*, developing coxa of fourth-stage male.
*putr*, developing trochanter of fourth-stage male.
*pw*, postalar bridge.
*r*, rostrum.
*ra*, raised area of head.
*rad*, radial vein.
*rap*, rudimentary anterior plate.
*rc*, rostral condyle.

*rg*, ring of genaceroris.
*ri*, ridge.
*r5l*, *r6l*, rudimentary fifth and sixth lobes.
*rol*, rostralis loop.
*ros*, rostralis.
*rpp*, rudimentary posterior plate.
*1rsc*, *2rsc*, first and second rostral sclerites.
*rsg*, rostral groove.
*sad*, salivary duct.
*sap*, salivary pump.
*sas*, small antennal seta.
*1sat*, *2sat*, first and second salivary tendons.
*sbp*, suture between maxillary brace and process.
*sc*, subcostal vein.
*scl*, mesothoracic scutellum.
*sct*, mesothoracic scutum.
*sdc*, salivary-duct bulblike chamber.
*sep*, secondary pore.
*ses*, apparent suture between sixth and seventh abdominal segments.
*skc*, condyle of ventral surface membrane.
*slp*, spinelike process.
*smp*, submarginal pore.
*sp*, spiracle.
*spa*, spiracularia.
*spc*, spiraceroris.
*spi*, spinelike projection.
*spl*, salivary plunger.
*sps*, spiracular submarginal seta.
*spu*, spur.
*sr*, sclerotic ring.
*srp*, submarginal raised pore.
*srs*, small rostral seta.
*ss*, submarginal seta.
*sss*, secondary submarginal seta.
*st*, stylus.
*str*, spinelike thickening of rostrum.
*sua*, superarca.
*suc*, supercosta.
*sw*, swellings of genital sheath.
*t*, trachea.
*ta*, tarsus.
*te*, teeth.
*teg*, tegula.
*ti*, tibia.
*tpl*, tendon of salivary plunger.
*tpw*, thickening of pharyngeal wall.
*tr*, trochanter.
*ucha*, undetermined sclerotic area.
*usc*, undetermined sclerite.
*va*, vagina.
*vb*, ventral band.
*vcha*, vaginal sclerotic area.
*vma*, ventral membranous area.
*vmep*, ventral mesal pore.
*vms*, ventral marginal seta.
*8vms*, *9vms*, eighth and ninth ventral marginal setae.
*vp*, process on ventral surface.
*vpr*, ventral prominence at apex of rostrum.
*vs*, ventral surface.
*vsr*, ventral surface ridge.
*vu*, vulva.
*vucha*, vulvular sclerotic area.
*w*, wing or wing pad.

| | |
|---|---|
| Broken lines | Ridges (or indicating connections between different aspects of the same structure). |
| Cross hatching | Space. |
| Dashes | Sclerotic parts or a solid background. |
| Dotted lines | Outlines of structures below surface. |
| Stippled areas | Membranous tissue. |
| Wavy lines | Tendonous tissue. |

## EXTERNAL ANATOMY

### EGG

The cuticle of the egg was too delicate to show any features, except a single pair of spines (fig. 1, *G*, *H*) situated near the ventrocephalic margin of the head. These spines showed slight variations in form and degree of sclerotization. They were approximately 4$\mu$ in diameter and only moderately raised above the surface.

### FIRST STAGE (MALE AND FEMALE)

Twenty-eight males in process of molting, at which time the sex can be determined by the presence of the second-instar male within the first-instar cuticle, all possessed a single prominent spur (fig. 1, *A*, *spu*) on the outer margin of the tibia. This spur appears to be a stout seta, though the presence of the calyx is difficult to detect with certainty. Twenty-four specimens definitely determined to

be females showed the following conditions regarding this spur: 16 had no spur on any leg; of those with a single spur, 2 had it on the right prothoracic, 1 on the left prothoracic, and 2 on the left metathoracic leg; of the 3 individuals with 2 spurs, 1 had these on both prothoracic legs, 1 on the right prothoracic and right metathoracic legs, and 1 on the right prothoracic and right mesothoracic legs. Many other individuals were observed from time to time in which there occurred either a single spur on all 6 legs, suggesting the male, or, usually, none on any leg, suggesting the female. Occasionally 1 spur occurred on 1 leg, but rarely were there 2 on any 2 legs, again suggesting the female.

The foregoing data regarding the presence or absence of this spur indicate that there is sex differentiation in this stage. Since no other sexual characters were discovered, however, it appeared desirable to discuss the two sexes of this stage together. Two of each sex from each of the four palms, 16 in all, were studied in detail.

The contour of the body is roundly oval at first, as shown in figure 1, *A*, which represents a newly hatched male from a Canary Island palm. The average length and width of 12 males and 14 females that were newly hatched were 0.26 and 0.16 mm, respectively. In individuals ready to molt the lateral contour is somewhat more sharply oval. The average length and width, respectively, of 26 males ready to molt collected from the four host palms were 0.39 and 0.28 mm, and of 21 such females, 0.41 and 0.29 mm.

## DORSAL ASPECT OF THE BODY

### BODY SEGMENTS

The pygidium is considered to be composed of four segments, the sixth to the ninth abdominal, inclusive, on the basis of the number and position of the setae, pores, plates, and lobes. It is a fused piece in which the segments are indistinguishable apart except for the presence of the caudal portion of what is considered to be the suture (*ses*) between the sixth and seventh abdominal segments. There are several distinct areas in the younger nymphs, but as the individual develops the sclerotization becomes heavy and gradually covers the whole pygidium. The general size and shape of the remaining body segments are indicated in figure 1, *A*.

### SETAE

Four large setae, the border head setae (*bhs*), are invariably located on each side along the margin of the head. Posterior to the two cephalic border head setae occur two smaller setae, the mesal head setae (*mhs*). Posterior to the mesal head setae is a smaller one, the caudal head seta (*chs*). All the setae on the head are situated typically as represented in figure 1. Located mesally on the thorax and abdomen is a characteristic curved row of six small setae, the mesal setae (*mes*). The cephalic one is near the meson apparently on the prothorax. The other five occur successively on the immediately following segments. In two specimens there was no seta on either side of the third abdominal segment. Nearly half way between the meson and the margin on the mesothorax and on the metathorax are setae that are slightly larger than the mesal setae and

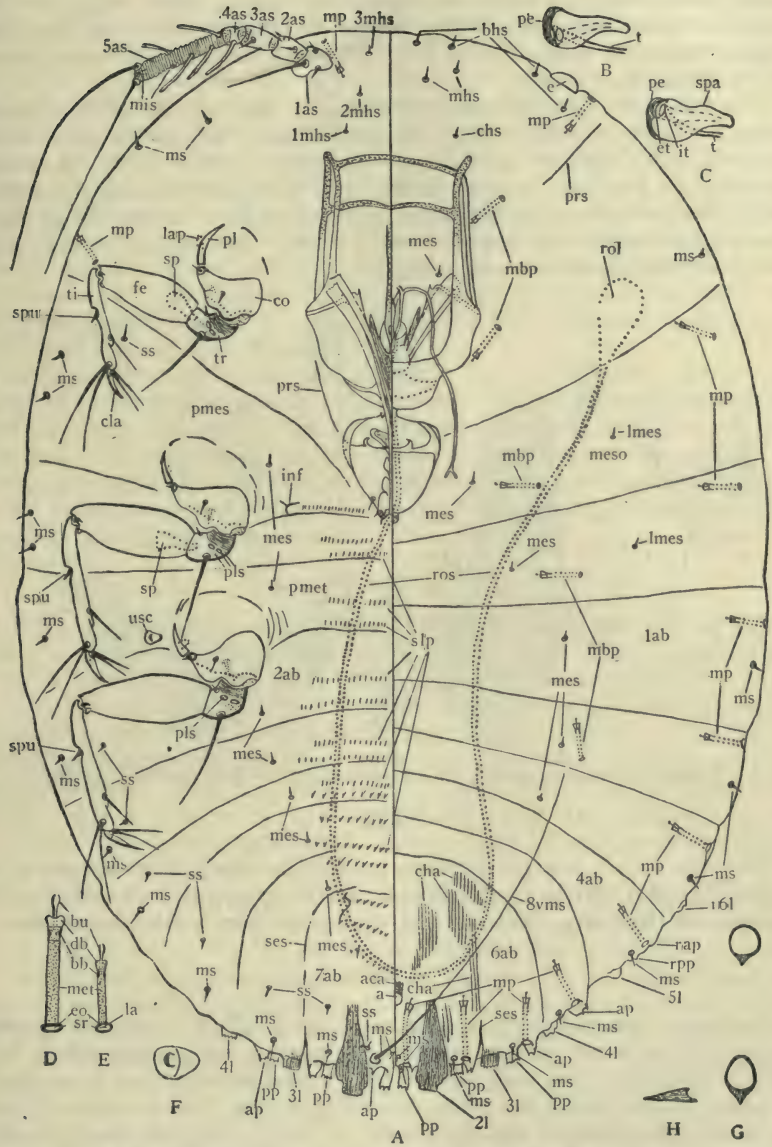


FIGURE 1.—*A*, Body, first-stage male (dorsal surface at right of observer); *B*, mesothoracic spiracle, first-stage male; *C*, metathoracic spiracle, first-stage male; *D*, marginal pore of eighth abdominal segment, first-stage male; *E*, dorsal marginal pore of head, first-stage male; *F*, undetermined sclerite laterad of metathoracic leg, first-stage male; *G*, pair of egg spines (approximate distance apart as indicated); *H*, egg spine, lateral aspect. *A*, × 540; *B–H*, × 1,000.

are called the lateral mesal setae (*lmes*). These two setae are constant in occurrence and almost so in position. Near the margin apparently on the prothorax and along the margin of apparently each abdominal segment at regular intervals also occurs a seta, called a marginal seta (*ms*). What is considered to be the ninth abdominal seta (fig. 2, *9abs*) is crowded beyond the margin and much reduced in size.

The average diameters, in microns, of the calyces of the various groups of dorsal setae of the head and body are as follows: Sixth, seventh, and eighth abdominal marginal, 2.3; fifth abdominal marginal, 1.9; first, second, third, and fourth abdominal marginal and anterior border head (three), 1.5; posterior border head, mesal head, prothoracic marginal, lateral mesal, 1.4; caudal head, mesal body, and ninth abdominal marginal, 1.2.

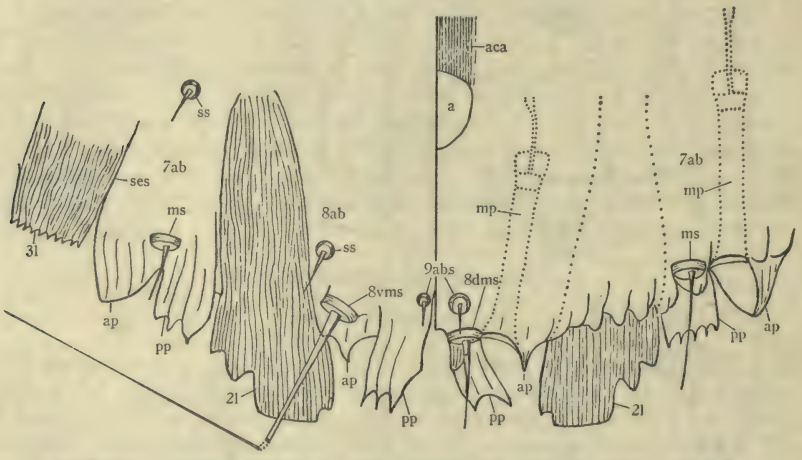


FIGURE 2.—Caudal margin of the abdomen, first-stage male. ×2,000.

EYE

The eye (*e*) is always present as a dome-shaped structure, about 8$\mu$ in diameter by 3$\mu$ in thickness, and ordinarily is situated on the margin of the body, between the two posterior border head setae.

PORES

Only one kind of pore is present (fig. 1, *D*, *E*), the invaginated tubular type having an external opening (*eo*) surrounded by a lightly sclerotic ring (*sr*) and a long delicate tube (*met*) ending in two bars. The basal bar (*bb*), which is apparently a union of what is usually considered the two bars of the pores of other diaspine species, is but little more sclerotic than the tube, and of about the same width, but it is distinctly heavier on the lateral margin. The distal bar (*db*) normally is expanded somewhat apically, more heavily sclerotic than the basal one, and capped by the "bulla" (*bu*) of MacGillivray (*8*, *p. 223*), a structure extending through the distal bar, narrow at the base and expanded apically. It is probable that the secretions pass from the wax cell through the bulla.

There is a series of pores along the margin of the body, one on each segment except the ninth abdominal one, which is too small to possess a pore (fig. 2). On the prothorax the pore is on the ventral surface. The head is peculiar in possessing two pores, the caudal pore on the dorsal surface and the cephalic one on the ventral, and known, respectively, as the ventral and dorsal marginal pores (*mp*). The largest pore is on the eighth abdominal segment, and measures uniformly about 15$\mu$ from the external opening, which is about 1.7$\mu$ wide, to the apex of the distal bar. The tube and the external opening are of practically the same width. The pores gradually decrease in size toward the head, the head pores being 9.5$\mu$ long and having a tube width of 1.2$\mu$. The external opening does not decrease in the same proportion as the tube, and on the head the latter appears to expand somewhat on reaching the exterior. No marginal pore was ever observed to be absent. These pores are always located cephalad of the marginal setae of this surface on the two posterior segments of the thorax and on the abdomen.

Pores occur mesally on the thoracic and the second abdominal segments and are of about the same size as the marginal pores of the same segments. They always occur laterad of the mesal setae of these segments and may be called the mesal body pores (*mbp*). One of these pores is so situated that it is difficult to determine whether it is on the prothorax or the head. On two specimens of each sex the metathoracic pores were absent.

### PLATES

On the pygidium are three sets of projections that may be called plates (*ap*, *pp*), the "squamulae" of Green (*4*). The cephalic half of the anterior plate of each set nearly always projects to a point and is slightly sclerotic. Its posterior margin makes a distinct curve caudad toward a pore, merging with the ring of the pore. The caudal half of each anterior plate is a little less sclerotic, and may or may not be toothed. The posterior plate of each set is characteristically broad, with a toothed distal margin, delicate and difficult to see except in well-stained specimens. At the base of each posterior plate is a dorsal marginal seta.

The plates on the eighth abdominal segment will be called the first or median set of plates, those on the seventh segment the second set of plates, and those on the sixth segment the third set of plates. On the fourth and fifth abdominal segments anterior plates may or may not be present, but usually are found on at least one side of the meson. Posterior plates of these segments seemed to be absent, or at most rudimentary, though there was occasionally a slight bulging. In figure 1 is a good example of rudimentary plates on the fourth abdominal segment (*rap*, *rpp*). The plates seem unquestionably to have arisen as bulgings from the body margin. Owing to the rudimentary condition of some of them, their exact number is sometimes doubtful. An examination of 2 male and 2 female specimens from each of the 4 host palms revealed much variation in the development of the 3 posterior pairs of these plates. The first or inner pair was sometimes absent, and the number of teeth ranged from 2 to 4, with an average of almost exactly 3. In only one specimen was the second pair of plates lacking, and the plates that were dentate had from 3 to

6 teeth, with an average of 4.7. A few of the third plates were also lacking, 2 were rudimentary only, and the remainder showed from 2 to 6 teeth, with an average of exactly 4.

LOBES

The marginal lobes (*1l* to *5l*) are also apparently outgrowths from the caudal margin of the body. When large and heavily sclerotic, they are easily recognized. The smaller and more delicate ones might be overlooked except through careful observation, especially as to their positions with regard to the neighboring setae, pores, and plates. For example, a lobe occurs immediately caudad of a marginal seta and pore on abdominal segments 5, 6, and 7, and sometimes the fourth abdominal segment appears to possess a lobe. Each one is in the same relative position with respect to the setae, pores, and plates of that segment. The first lobe is apparently absent (fig. 2). The position of the large, strongly sclerotic lobe indicates rather certainly that it is the second lobe.

The dimensions and extent of notching or dentation of these marginal lobes in 2 female and 2 male specimens from each of the 4 host palms may be summarized as follows: The second lobe varied only slightly in dimensions, the length ranging from 19 to 23$\mu$, with the average 22$\mu$, and the width from 6 to 7$\mu$, with the average 6.75$\mu$. Except in a single specimen, in which it was entire, the margin of this lobe had a distinct notch at the inner apical corner, and usually 1, but sometimes 2, comparable notches in the outer lateral edge. The lightly sclerotic and distally slightly convex third lobe ranged in length, as measured from body margin to tip, from 1 to 4$\mu$, with the average 2.1$\mu$, and had a width range of from 1 to 6$\mu$, with the average 5.2$\mu$. The width was usually more than twice the length. The apical margin was frequently minutely serrate, but more often exhibited from 3 to 7 teeth, or an average of 4.3. The nonsclerotic and variable fourth lobe may be rudimentary or lacking; when present it may be pointed or rounded at the apex or more or less truncate, and either serrate or with from 2 to 8 teeth on the outer margin. The length of the fourth lobe in the individuals showing it ranged from 1 to 4$\mu$, with an average of 1.8$\mu$; the width ranged from 1.5 to 8$\mu$, with an average of 4.5$\mu$. The fifth lobe was rarely present and resembled the fourth in its variability. Its length ranged from 1 to 2$\mu$, with an average of 1.6$\mu$; its width from 1 to 6$\mu$, with an average of 3.6$\mu$. With the exception of one side of one specimen, on which 6 teeth were found, this lobe was neither serrate nor dentate at the apex. In most of the individuals a slight bulge occurred on the third abdominal segment, which might be taken for a sixth lobe (*r6l*). This slight bulge also occurred on the fourth segment in nearly every case, but in most instances it was not sufficiently differentiated from the margin to be considered a separate structure. Even the fourth lobe may sometimes be considered to be rudimentary, as when only 1 to 1.5$\mu$ in length. Indeed, only the second and third lobes would usually be observed as such. It is readily seen that in this stage the number of lobes would be practically worthless as a point in classification. The number of notches would also have to be used with caution, for the number on different individuals, and even on the lobes of the two sides of the same individual, fre-

quently differs, and there may even be no notches at all. The number of teeth of the third lobe could hardly prove of value, for not only do they vary but they may be reduced to hardly more than serrations.

#### ANUS

The anus (*a*) in 13 individuals averaged 6$\mu$ in diameter and was located approximately 23$\mu$ cephalad of the caudal margin of the second lobe. There was little difference in this position in young and old individuals. The position of the anus with respect to the segments could not be determined with certainty. A sclerotic area (*aca*) is always present immediately cephalad of it, and extends partly down on the sides.

### VENTRAL ASPECT OF THE BODY

#### BODY SEGMENTS

There is no indication of sutures between the head, prothorax, and anterior section of the mesothorax, except possibly caudomesally between the head and prothorax, but the segmentation of the remaining thoracic segments is distinguishable practically throughout. The metathoracic leg lies sufficiently caudad to bulge against the second abdominal segment. The succeeding abdominal segments to and including the sixth are distinct. This means that the pygidium, if considered to be the single inflexible caudal piece, includes for this surface three segments, the seventh, eighth, and ninth abdominal ones. There are no particular areas on the ventral surface of the pygidium, though it is more heavily sclerotic than the remainder of the surface. Its sclerotization, however, is somewhat less marked than on the dorsum. Cephalomesad on the pygidium are at least three rows of small spinelike processes (*slp*). Two rows of these little processes occur on every segment along the meson, cephalad to the mesothorax, which, however, has but one. A rather small invagination, called the intersegmental furca (*inf*), occasionally occurs between the mesothorax and the metathorax. The size of the segments is much the same as on the dorsal surface. The ninth abdominal segment is distinctly invaginated and greatly reduced in size (fig. 2).

#### ANTENNA

The length and width of each of the five segments of both antennae of each of the 16 individuals were measured. These measurements, in microns, were as follows: Basal, length range 8 to 11, average 9.4, width range 10 to 12, average 11; second, length range 7 to 10, average 8.3, width range 6 to 8, average 7.1; third, length range 7 to 9, average 8.5, width range 6 to 7, average 6.4; fourth, length range 4 to 6, average 5.2, width range 5 to 6, average 5.5; fifth, length range 24 to 29, average 26, width 6.

All the basal segments possessed 1 long and 2 relatively small setae; the second segments, 2 small setae; the third, 1 seta; and the fourth, 1 moderately long fleshy seta. There was no appreciable variation in the number and size of these setae on any specimen. Some variation did occur, however, on the fifth segment, where from 3 to 5 fleshy setae were found, the number present sometimes being different on the antennae of the same individuals. Their position on the segment

varies freely. Two very long and slender setae arise from the distal end of the segment. There are also two small structures, which from the resemblance to similar structures in other scale insects may be considered as minute invaginated setae (*mis*), always present on this segment as figured.

SETAE

Between the antennae are three small setae on each side (*1mhs to 3mhs*); none of these was ever observed to be absent. Eight mesal setae (*mes*) were always found on the thoracic and abdominal segments.

A pair of large setae, the marginal setae (*ms*), occur near the margin of each of the following segments: Mesoprothorax, posterior section of the mesothorax, and anterior section of the metathorax. The cephalic one of each pair is usually more mesad than the other. Sometimes one or both are almost, if not quite, on the dorsal surface. The marginal setae continue caudad, one on each of the abdominal segments. They are similar in size to the thoracic setae, except for the eighth abdominal one (*8vms*, fig. 2), which is very large and long, and the ninth abdominal one (*9abs*, fig. 2), which, in contrast to the eighth, is extremely small, in fact the smallest seta on the body. A ventral and a dorsal marginal seta of the abdomen constitute a pair in the same series with the thoracic pairs. The ventral ones are always cephalad of the dorsal ones. No seta of these pairs was ever missing.

Along the submargin of the body there is a row of small setae, one on each abdominal segment except the first and the ninth, which may be known as the ventral submarginal setae (*ss*). Each one is always present, and comparatively constant in position. On the posterior section of the mesothorax, near its cephalic border and about two thirds of the distance to the margin, is a seta which should probably be included in the submarginal series. It is larger than the other submarginal setae, but not so large as the marginal pairs.

The ventral setae may be grouped as follows according to the calyx diameters in microns: With diameter 2.7, the eighth abdominal marginal; with 1.9, the fifth, sixth, and seventh abdominal marginal; with 1.7, the thoracic marginal and the first to fourth, inclusive, abdominal marginal; with 1.5, the mesothoracic submarginal; with 1.2, the mesal head, mesal body, and remaining submarginal; with 0.8, the ninth abdominal marginal.

LEGS

The three legs are similar in every noticeable respect (except possibly size), including the number, size, and position of the setae on the sclerites; therefore, a description of one will apply to all. Distally the coxa (*co*) bears two large acetabula, and between these a large, broadly rounded condyle, articulating against two large, rather sharp pointed condyles of the trochanter, apparently allowing a limited rocking motion. At the base it is drawn out into a narrow, strongly sclerotic condyle, that articulates nearly flatly against a prominent sclerite, which MacGillivray has called the "episternum" but is termed here simply the "pleural sclerite" (*pl*). There is probably a rather limited action between the coxa and the pleural sclerite. The latter possesses an internal projection, usually stout

and rounded, designated as the "lateral apodeme" (*lap*). The trochanter (*tr*) articulates freely against the coxa. The femur (*fe*) is apparently rigidly attached to the trochanter, but articulates freely against the tibia (*ti*) by means of two small condyles, the cephalic one strongly sclerotic and the caudal one membranous. The tibia and tarsus are apparently fused. The claw (*cla*) is toothless.

The length and width of all segments of all 6 legs were measured for each of the 16 individuals. As would be expected, slight variations were noted even on different sides of the same individual. There was also a slight variation in average size of the segments, the prothoracic ones being the smallest and the mesothoracic ones next. The range and the average of the length and width of the parts of the metathoracic leg, expressed in microns, are as follows: Coxa, length range 16 to 21, average 18.4, width range 12 to 16, average 13.6; trochanter, length range 10 to 13, average 12.1, width range 8 to 10, average 9; femur, length range 29 to 35, average 32.3, width range 12 to 13, average 12.2; tibia plus tarsus, length range 28 to 35, average 32.1, width range 5 to 6, average 5.8; claw, length range 12 to 16, average 13.4, width 3.

The coxa bears 3 small setae, 1 of them on the dorsal surface. The seta situated near the basal condyle is easily overlooked. The trochanter bears 2 setae, both on the ventral surface, 1 very large, the other very small and easily missed. In addition, there are 4 porelike structures (*pls*), 2 each on opposite surfaces. The femur bears no setae. The tibia-tarsus has, besides the spur previously discussed, 1 moderately large seta on the inner surface, immediately cepalad of a notch. Two long setae occur at the distal end on the outer margin. The inner surface of the thickened base of the claw also bears a pair of setae.

### SPIRACLES

In mounted material the spiracles (*sp*) are usually hidden by the legs. The spiracle proper is considered as merely the external opening, which is rather large and surrounded by a prominent sclerite, the peritreme (fig. 1, *B*, *C*, *pe*). In all specimens the peritreme appeared crescent-shaped, the ring being unrecognizable. The trachea (*t*) decreases in diameter from the spiracle. A crescent-shaped sclerotic area, the external thickening (*et*) of the trachea, occurs not far within. Somewhat farther inside occurs a ringlike sclerotic area, the internal thickening (*it*), which is of the same diameter as the trachea proper. The somewhat trumpet-shaped sclerite attached to the peritreme has been called by MacGillivray the "spiracularia" (*spa*). In this stage its small end is directed mesad. The two pairs of spiracles are nearly equal in size. The diameter of the peritreme, meaning the straight distance across the largest crescent-shaped sclerite, is typically about 6$\mu$. The spiracularia is about 12$\mu$ long and is curved, with one or more ridges extending the length of it.

On the posterior section of the metathorax laterad of the leg is a strongly sclerotic structure (*usc*) typically of the size and shape shown in figure 1, *A*, *F*. It possesses an inner curving piece which resembles the peritreme of a spiracle. It is always present. If the segment laterad of the leg is considered to be a part of the first abdominal segment, this sclerite is in position to be a vestigial spiracle.

#### ROSTRALIS [3]

One structure associated with the endoskeleton of the head, the mouth-stylets bundle or rostralis (*ros*, *rol*), will be discussed here, as regards its position and dimensions, because of the excellent comparisons that can be made between it and other body parts. The rostralis, in issuing from the head, is always directed caudad within the body nearly to the anal opening, where it bends deeply cephalad, curving gently, first mesad and finally laterad, to the prothorax, where it forms a loop and retraces its path as far as the base of the rostrum. The length of the rostralis from the bases of the mandibles and maxillae to its tip varies with the individual. Its average length in 17 specimens was 0.64 mm, the shortest being 0.59 mm and the longest 0.77 mm.

### SECOND-STAGE FEMALE

Twenty individuals, 8 from date palm and 4 each from the other 3 palms, were studied. In newly molted ones, as represented in figure 3, *A*, the contour of the body is roundly oval, somewhat sharper at the ends than in newly hatched first-stage nymphs. The average length of 15 newly molted individuals was 0.39 mm, and the average width 0.30 mm.

#### DORSAL ASPECT OF THE BODY

##### BODY SEGMENT

The pygidium is more extensive than in the first stage, for the rudiments of the suture between the sixth and seventh segments are absent. The segments of the pygidium are easily determined from the number and position of the setae, pores, plates, and lobes in this region. The ninth segment is much less reduced than in the first stage. The sclerotic areas of the pygidium are well defined in the newly molted specimens, and practically uniform in appearance. A distinctive, small, acutely oval sclerotic area is situated submarginally on the sixth abdominal segment (*ucha*). In older individuals the sclerotization spreads over the entire pygidium, obliterating any definite sclerotic areas. In the younger specimens, however, these areas can be homologized with those of the first stage. The remaining segments of the body are essentially like those in the preceding stage.

##### SETAE

Four large cephalic setae and one smaller caudal seta (*bhs*) are always present near the margin of the head, on each side of the meson. The exact position of each may vary somewhat, but the general position is as shown. In 3 individuals a still smaller seta was also present posterior to them, in 1 case occurring on both sides and in the other 2 on one side only. On another specimen a large seta occurred on each side, anterior to the 5 usual ones. On 5 specimens this kind of seta occurred on one side only. These were the only exceptions observed. These setae appear to be homologous with those of the first stage, and therefore may be called the border head setae.

[3] This term is used for the parts involved throughout this bulletin, the reasons for its use being given on p. 54.

The smaller posterior seta is an extra one in this stage, but is considered as belonging to this group. The pair of mesal head setae of the first stage were not observed.

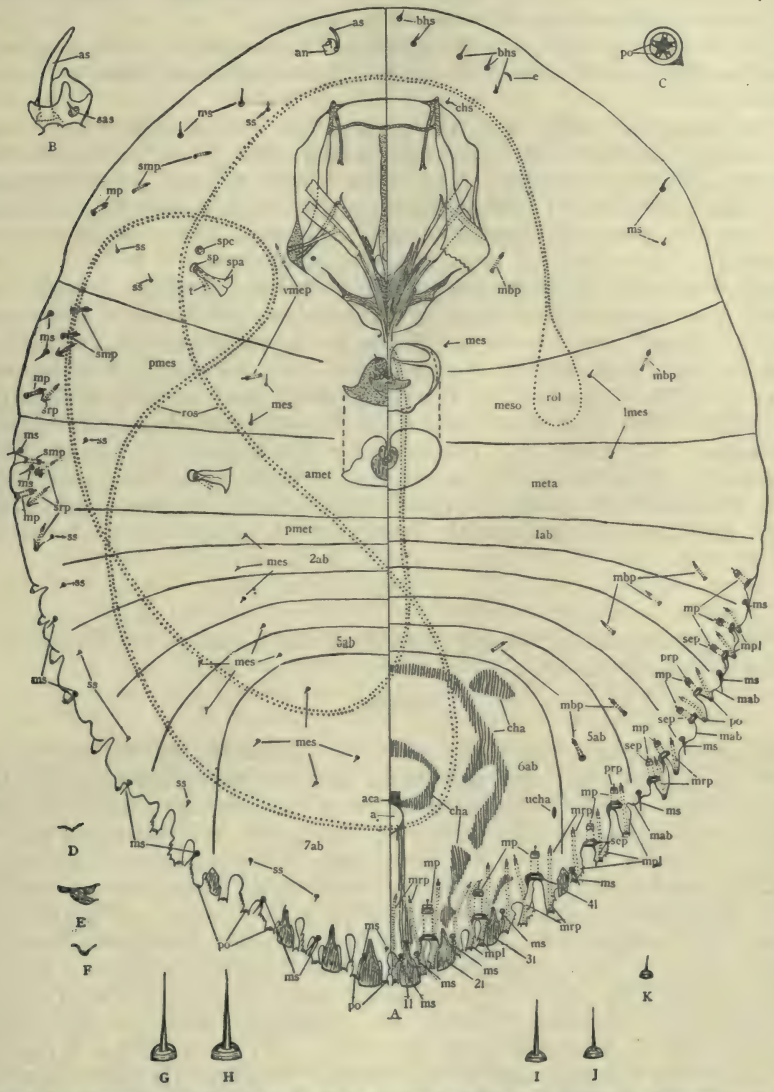


FIGURE 3.—Second-stage female: *A*, Body (dorsal surface at right of observer); *B*, antenna; *C*, spiraceroris; *D*, prothoracic leg; *E*, mesothoracic leg; *F*, metathoracic leg; *G*, dorsal marginal seta of first abdominal segment; *H*, large dorsal marginal seta of fifth abdominal segment; *I*, ventral marginal seta of eighth abdominal segment; *J*, mesal body seta; *K*, ventral marginal seta of ninth abdominal segment. *A*, ×320; *B-K*, ×1,025.

A small seta (*chs*) always occurs, generally cephalolaterad but sometimes immediately cephalad of the endoskeleton. It is considered to be homologous with the caudal head seta of the first stage.

The mesal setae, except what is considered to be the prothoracic one, are lacking in this stage. This seta (*mes*) does not occur in the

first stage, but occurs in the second-stage male, as well as all the other setae of this set. It was missing on both sides in two specimens; in another specimen it was absent only from one side; in all the other specimens it was present on both sides. It is evident, however, that it is not a constant structure in this stage.

Two lateral mesal setae are situated in essentially the same locations as they are in the first stage. None was ever observed to be missing.

The marginal setae are all present as in the first stage. An additional, smaller seta occurs associated with, and caudomesad of, the prothoracic marginal one. Two plates always occur between the setae on the first 4 abdominal segments, 3 plates between them on the next 3 posterior segments, and 2 between them on the eighth segment. The marginal setae are always present.

All the setae of this surface show rather closely, though not exactly, a characteristic size. For instance, no "small" seta ever occurs "large", or vice versa. These dorsal setae may be grouped as follows on the basis of measurements, in microns, of numerous calyces: With diameter 3.2, the fifth, sixth, and seventh abdominal marginal; with diameter 3, the four large border head, the eighth abdominal marginal, and the anterior prothoracic marginal; with diameter 2.3, first to fourth, inclusive, and ninth abdominal marginal; with diameter 1.9, posterior prothoracic marginal, posterior border head, and lateral mesal; with diameter 1.5, caudal head and mesal body.

#### EYE

The eye is nearly always distinguishable, but is evidently in a vestigial condition.

#### PORES

In the first stage the pores show no particular variations except that in general they are somewhat smaller anteriorward. In the second-stage female the pores show a considerable range in size, shape, and degree of sclerotization. No pores were observed on the head. In most instances a minute pore (*mbp*), rather variable in position, was noted on the prothorax and on the mesothorax. On the first abdominal segment 1 marginal pore is present, as in the first stage; on the second to fifth abdominal segments, inclusive, 2 occur; on the sixth, seventh, and eighth abdominal segments there is only 1, and on the ninth none. The marginal pores are situated at the head of prominent incisions, which are especially deep on the sixth, seventh, and eighth abdominal segments. On the segments having 2 incisions the anterior one is always the deeper. In this stage the marginal pores are shorter and broader than in the first stage, and the rings about the external openings are more strongly sclerotic. The basal bars are broader and also much more strongly sclerotic, but the distal bars are narrow and the sclerotization is relatively slight. The bulla is practically the same in the two stages. As in the first stage, the size of the pores gradually decreases cephalad. For example, a typical pore on the eighth segment, measured from the external opening to the distal border of the distal bar, was 13$\mu$ long, the width of the basal bar 5.5$\mu$, and the width of the sclerotic

ring about the opening 8$\mu$; in contrast, a pore of the first segment, measured over the same limits, was 8.6$\mu$ long, 3.5$\mu$ across the basal bar, and 5$\mu$ across the sclerotic ring.

Sometimes a marginal pore was absent. Of the 20 specimens studied, 7 lacked, on the dextron, the posterior pore of the fifth segment, 1 lacked, on the sinistron, the posterior pore of this segment, while 1 lacked also, on the dextron, the posterior pore of the fourth abdominal segment. Only in these instances were missing pores noted. Apparently the extra pores of these 2 segments, especially those of the fifth segment, are not so well established as those of segments 2 and 3. The fact that, where a segment normally has 2 pores, the anterior one is always present seems to indicate that it is the primary pore (*prp*), that is, the pore homologous with the one on that segment in the first stage.

The mesal pores of the first stage are probably represented in this one by a series of small pores (*mbp*) found, for the most part, along the submargin of the body. They are much smaller than those of the first stage. On the abdominal segments they are clearly distinguished from the marginal pores by their size and position. A small pore occurs typically on each of the first 5 abdominal segments, the one on the fifth being usually somewhat larger than the others, and the one on the fourth frequently so. The pore on the third abdominal segment is generally distinctly more mesad than the others. The position of these pores along the submargin varies considerably in different individuals. The size of the 2 pores on segments 4 and 5 varies considerably. Also, 1 or more of them may be lacking on one or both sides of the body. Contrariwise, there may be more pores present than the typical 5 on either or both sides, and 1 may occur on one or both sides of the sixth segment, in which case the additional pores are generally considerably mesad of the others. In short, this series of pores is decidedly unstable in character. The dimensions of the small pores, in microns, are about as follows: Length from external opening to distal border of distal bar 5, width of bars and tube 1, width of ring about opening 1.9.

The caudal margin of the body bears a series of long, narrow, delicate pores, the marginal raised pores (*mrp*), which always open at the distal ends of projections; therefore, if a projection is lacking, so is the pore. These projections are the plates subsequently discussed. The caudal pores average about 35$\mu$ in length. There is a gradual decrease until they average but 13$\mu$ in length on the first, second, and third segments. The tubes are flexible, and may curve moderately or sharply to either right or left. The bars are similar in form and sclerotization to those of the mesal body pores, but the distal ones are normally somewhat expanded. On the other hand, these distal bars may be found in a collapsed condition (fig. 5, *L*), as are occasionally any of the smaller pores of the body. The rings are little, if at all, expanded, owing undoubtedly to their confined limits on the plates.

### PLATES

Typically 18 marginal plates (*mpl*) are present on each side of the body. Rarely 1 or 2 may be absent or an additional 1 may be present. They vary somewhat in size and shape, more so on ab-

dominal segments 5 and 6 than on the other segments. These plates appear to be undifferentiated projections of the margin.

The plates on the five posterior segments usually have small, sharp projections, called "teeth." A prominent distal, forked pair is nearly always present, except on the plates of abdominal segment 5. The anterior plate of this segment rarely is toothed, and the 2 posterior plates either have no teeth or a varying number up to 10, usually 5 or 6, irregular in size and position. The plates of abdominal segment 6 bear a large number of teeth, the forked distal ones and generally 3 or 4 additional lateral ones, sometimes more or less, and sometimes 1 or 2 teeth may occur on the mesal side of the plate. The plates of abdominal segments 7, 8, and 9 bear characteristically the distal forked ones and but rarely more than 1 or 2 in addition. On the anterior plates, and on the single plate on segment 9, the additional teeth are typically on the mesal sides; on the other plates, typically on the lateral sides. The teeth may be rather difficult to see, even on nicely stained specimens. They occur in all sizes, some distinct, others so infinitesimal that it is a question whether they are present at all. Furthermore, it is sometimes doubtful whether a toothlike projection is really on a plate or merely on the inner margin of the body proper.

Although the marginal raised pores never appear apart from the plates, some of the plates occasionally occur devoid of pores. The poreless plates were seen only on the fifth and sixth abdominal segments and were always in a rudimentary condition.

Structurally the marginal plates appear to be similar to the submarginal raised pores of the thoracic segments and are considered homologous with them.

### LOBES

The number of lobes on each side in this stage is, rather definitely, 4. The locations for the fifth, sixth, and seventh lobes are indicated, however, by marginal bulgings (*mab*). The typical size and shape of the lobes is shown in figure 3, *A*. The measurements, in microns, of the lobes on the 20 specimens studied were as follows: First lobe, length range 14 to 21, average 17.2, width range 7 to 9, average 8.6; second lobe, length range 13 to 18, average 14.9, width range 5 to 7, average 6.1; third lobe, length range 7 to 16, average 12.2, width range 3 to 7, average 5.5; fourth lobe, length range 5 to 16, average 10.6, width range 3 to 7, average 5.2.

The first 3 pairs of lobes were always present and distinctly sclerotic, the third pair a little less so, apparently, than the preceding 2, and they showed practically no variation from the typical shape. The first 2 pairs always had even apical contours; the third pair, however, possessed a distinct lateral notch on each side of the meson in 2 specimens, and in another specimen 1 of the third pair was irregularly margined. The third pair also showed a wider range of dimensions than the other 2; in short, it was less fixed in its characteristics. The fourth pair of lobes were even less fixed than the third. In about half the individuals they were not much less sclerotic than the third pair; in other specimens little or no sclerotization was noted. In half of the individuals the apical contour of the fourth lobe was very nearly, if not quite, even. The fourth lobe had distinctly irregular apical contours on both sides of the meson

in 7 specimens, and on one side only in 2 specimens. Another individual had a typical notch on the fourth lobe on each side of the meson. The variation in size was more marked than in the third pair. In 1 individual the fourth lobe could not be distinguished on one side, and in many specimens it might easily have been overlooked by one unfamiliar with its characteristics.

#### ANUS

The anus averaged 10$\mu$ in diameter for the 20 individuals studied; the range was slight, from 9 to 12$\mu$. The distance on the dorsal surface from the distal margin of the median lobes ranged from 60 to 77$\mu$, with an average of 70$\mu$; the difference in distance appeared to be independent of the ages of individuals. A distinctly sclerotic column extends from the base of the median lobe to the lateral margin of the anus. This column is in the position where a suture would be expected, and may indicate the division between segments 8 and 9. The anus is situated along the cephalic margin of this column, and would, therefore, apparently be either between the eighth and ninth segments or along the cephalic margin of the latter. Most morphologists, however, consider the anus as belonging to the tenth segment in other insects. In this case the tenth segment would be reduced to an indistinguishable vestige. Rather significantly, another sclerotic column extends cephalad and mesad from the second lobe, in the position for a suture between segments 7 and 8. A heavily sclerotic square area (*aca*) was present as in the first stage, immediately cephalad of the anus.

### VENTRAL ASPECT OF THE BODY

#### BODY SEGMENTS

The segments are essentially like those of the preceding stage, except that there is no evidence of any suture between the sixth and seventh abdominal segments and the pygidium is somewhat more extensive.

#### ANTENNA

The antenna (*an*) is never absent. It is a tubercular structure (fig. 3, *B*) composed largely of what appear to be only 3 or usually 4 stout projections, irregular in size and position, that are frequently so smoothed out as to be scarcely, if at all, distinguishable from one another. The antenna bears a prominent seta (*as*), which is fleshy, characteristically curved, and uniformly about 12$\mu$ long. This seta was never absent. In about one fourth of the individuals a very small additional seta (*sas*) could be distinguished. This was absent, however, in the specimen figured. The positions of the setae on the antennae are not definite, owing to the irregularity of the projections on them. The antenna with its projections averages about as long as broad, that is, 7$\mu$.

#### SETAE

Of the mesal head setae, only the caudal pair was ever present. In 12 individuals, including the one figured, this seta was missing; in

the remaining 8 it was present on one or both sides. It is evident that these setae have nearly disappeared from this stage.

The mesal setae differ from those of the first stage in the addition of a seta on the mesothorax, giving this segment 2, and the addition of 1 seta on each of abdominal segments 4 to 7, inclusive. The extra ones are situated laterad of the primary setae, typically as shown in the figure. The primary setae are situated similarly to those in the first stage. As would be expected, none of the primary setae was ever absent, but in 3 specimens 1 of the new setae was lacking on the seventh abdominal segment.

The marginal setae occur similarly to those in the first stage, except for the lack of one on the posterior section of the metathorax, and the great reduction in size of the one on the eighth abdominal segment, which is here just slightly smaller than the others, and the one on the ninth, which is appreciably smaller but not so small as it is in the first stage. A slight variation in size is frequently observed among the other setae of this series. Measurements of the distance separating the two members of each of the thoracic pairs of these marginal setae in the 40 cases showed much variation, as indicated by the following enumeration, given in microns: Between prothoracic pair, 7 to 14; between mesothoracic, 14 to 36; between metathoracic, 20 to 43. The marginal setae were constant in their presence.

The submarginal setae differ from those of the preceding stage by the absence of the ones on the posterior section of the mesothorax and the eighth abdominal segment, and the presence of 1 on each of the 2 sections of the metathorax and of 3 on the mesoprothorax. The position of the submarginal setae is fixed on the abdomen, but considerably less so on the thoracic segments. The typical location of each is as represented in the figure. The seta of this series on the sinistron of the metathorax was absent in 1 individual, and the more laterad of the posterior setae from the dextron of the prothorax was absent in another individual.

The ventral setae may be arranged in the following groups on the basis of measurements, in microns, of the calyx diameters: With diameter 2.7, prothoracic and mesothoracic marginal; with diameter 2.3, first to seventh, inclusive, abdominal marginal, and metathoracic marginal; with diameter 1.9, mesothoracic mesal, pygidial mesal, eighth abdominal marginal, and mesoprothoracic anterior submarginal; with diameter 1.5, all other mesal and submarginal; with diameter 1.2, ninth abdominal marginal.

#### PORES

No pores were observed on the head. Near the margin of the thoracic segments, except the posterior section of the metathorax, a number of pores with surface openings occur. The posterior one (*mp*) on each segment, because of its generally slightly larger size, is considered to be homologous to the marginal pores; the others are called submarginal pores (*smp*) but appear to be a continuation of the mesal body pores (*mbp*) occurring on the dorsum of the abdomen. The submarginal pores on the mesoprothorax are distinctly smaller than the other submarginal pores. On the remaining 2 segments possessing them the submarginal pores vary somewhat in

size, and on all the segments they vary in position. The marginal pores seem to be constant in number, 1 occurring on each of the thoracic segments except the posterior section of the metathorax, which apparently lacks on this surface both marginal and submarginal pores. The submarginal pores vary in number. On the 20 specimens studied they occurred as follows, those on each side of the body being counted separately: On the mesoprothorax no pores in 3 cases, 1 pore in 2 cases, 2 pores in 12 cases, 3 pores in 22 cases, 4 pores in 1 case; posterior section of the mesothorax, 1 pore in 11 cases, 2 pores in 27 cases, 3 pores in 2 cases; anterior section of the metathorax, no pores in 11 cases, 1 pore in 29 cases. A count of the marginal and submarginal pores of both surfaces of the abdomen and thorax, up to and including the marginal pore of the mesoprothorax but not the little submarginal ones of this segment, of 178 specimens from all 4 host palms showed a range on each side of the body of 15 to 20 pores, and an average of 17.4 pores.

Near the meson on the mesoprothorax is a minute pore, about 5$\mu$ long by 0.7$\mu$ wide across the bars (fig. 5, *L*). The sclerotic ring is, however, about as wide as in the average small pore. In 2 specimens no pore was observed on one side. Another pore, almost equally as small, always occurs on the posterior section of the mesothorax, in the neighborhood of the anterior mesal seta. These 2 pores are called ventral mesal pores (*vmep*). Two were present on the dextron of the posterior section of the mesothorax of 1 individual.

No mesal pores were noted on the abdomen.

On the posterior section of the metathorax there is always a single raised pore. On each of the 2 immediately anterior segments—that is, the anterior section of the metathorax and the posterior section of the mesothorax—are usually 2, occasionally only 1, and rarely 3. On the mesoprothorax 1 individual possessed 1 pore on the dextron. These raised pores are considered to be merely a continuation of the raised pores from the margin of the abdomen on the dorsum, and are in every particular like the submarginal raised pores of the anterior abdominal segments of that surface. They may therefore be called the ventral submarginal raised pores (*srp*). There appears to be no clear connecting link between the raised pores and the surface pores. The former always have tubes longer in proportion to the width than the latter (fig. 5, *M*, *N*, *O*), and there never seems to be any doubt as to whether a pore is raised or not. However, the structural details of both are apparently identical, and so there is little doubt that they are homologous.

Pores of the disk type (*spc*) occur only on the mesoprothorax, immediately cephalad of each spiracle, the "spiraceroris" of MacGillivray (*8*). This term is considered more desirable than, for instance, "spiracular pore", because it makes it possible to distinguish clearly the types by name, and to distinguish these definitely from the 1 or 2 small mesal pores which also occur near the spiracles. The spiracerores (fig. 3, *C*) are slightly raised, doubly ringed, typically with a sharp sclerotic projection, a section of the lateral raised wall, extending from the outer ring to the body surface; and they bear from 2 to 5 pore openings, which are always located apparently at the ends of central sclerotic thickenings. In a pore with 5 openings the central thickening assumes the appearance of a star, with

the openings apparently in the apices of the rays. The spiracerores with 5 openings were all practically 4.5$\mu$ in diameter, and those with fewer pore openings were very slightly smaller, depending somewhat upon the number of openings. Occasionally the openings were too indistinct to count. The number of openings may vary on different sides of the meson of the same individual. One specimen possessed 1 pore with 5 openings on one side, and 2 pores, 1 with 5 and 1 with 3 openings, on the other side. In an examination of 195 specimens, in which each side of the body was counted separately, 3 pores occurred once and 2 pores six times; all the remaining specimens possessed 1 pore on each side.

#### LEGS

Certain vestigial protuberances (fig. 3, *D*, *E*, *F*), either membranous or sclerotic, or partly both, as occurs occasionally, may be considered as legs, since they are similar to larger structures in the same locations in the second-stage male which are definitely recognized as legs. Thirteen individuals had one or more of these protuberances. In one instance the protuberance, a mesothoracic one, was relatively large and somewhat sclerotic (fig. 3, *E*). Hoke (*6*) has mentioned the presence of vestigial legs in both this stage and the adult female of a leucaspid.

#### SPIRACLES

The spiracles (fig. 3, *A*, *sp*) differ from those of the preceding stage most noticeably in the fact that the larger ends of the spiracullariae are directed mesad, thus in opposite direction to those of the first stage. The peritreme is always ringlike in this stage. The tracheal thickenings and the ridge of the spiracullariae are present with modifications. The two pairs are subequal in size, about 20$\mu$ long, including the lateral boundary of the peritreme, by 8$\mu$ across the widest part of the spiracularia. The peritreme is almost uniformly 5$\mu$ in diameter.

#### ROSTRALIS

The rostralis is considerably longer in proportion to the size of the body than in the first stage. Measurements of its length in 8 specimens showed a range of from 2.31 to 2.70 mm, with an average of 2.53 mm. In the newly molted individual of this stage the rostralis is from 6 to 7 times the body length, whereas at the beginning of the first stage it is less than 3 times as long as the body. The position of the rostralis in the body of prepared specimens varies widely, no 2 individuals showing it alike. The end loop is rather definite in size, however, averaging 45$\mu$ long by 20$\mu$ wide. The rounded contour of the loop suggests its relative stiffness.

### ADULT FEMALE

Thirty-two individuals, eight from each palm, were studied. The contour of the body (fig. 4, *A*) is slightly elongate oval, broadest across the base of the posterior half, from which there is a rather sharp slope caudad and a gentle slope cephalad. The body does not change in shape and increases but little in size after molting. The average for a number of older individuals is somewhat larger, but

FIGURE 4.—Adult female: *A*, Body (dorsal surface at right of observer); *B*, *C*, antenna; *D*, posterior body pore of eighth abdominal segment; *E*, posterior body pore of seventh abdominal segment; *F*, cephalic submarginal pore of mesothorax; *G*, *H*, ventral mesal mesoprothoracic pores; *I*, marginal pore of posterior section of metathorax; *J*, mesal pore of mesal body series on dorsum of sixth abdominal segment; *K*, submarginal raised pore of metathorax; *L*, marginal pore of eighth abdominal segment; *M*, marginal pore of ninth abdominal segment; *N*, lateral aspect of genaceroris; *O*, genaceroris; *P*, spiracle and associated structures; *Q*, lateral aspect of genaceroris; *R*, posterior marginal raised pore of fifth abdominal segment; *S*, abdominal marginal fringe; *T*, ventral marginal seta of ninth abdominal segment; *U*, dorsal marginal seta of ninth abdominal segment; *V*, dorsal marginal seta of first abdominal segment; *W*, dorsal marginal seta of fifth abdominal segment; *X*, large dorsal marginal seta of fifth abdominal segment; *Y*, lateral aspect of posterior part of body. *A*, × 145; *B-O*, *Q*, *R*, *T-X*, × 1,000; *P*, × 555; *S*, × 425; *Y*, × 290.

frequently an overlapping of size among the individuals of different ages has been noted. A tabulation of lengths and widths of 45 newly molted specimens and of 40 older ovipositing specimens showed much variation throughout; it may be summarized as follows: Newly molted individuals, length 0.52 to 0.85 mm, average 0.7 mm, width 0.4 to 0.66 mm, average 0.53 mm; older ovipositing individuals, length 0.61 to 0.84 mm, average 0.74 mm, width 0.5 to 0.68 mm, average 0.59 mm.

### DORSAL ASPECT OF THE BODY

#### BODY SEGMENTS

The segments of the pygidium are differentiated in essentially the same way as in the preceding stages. The sclerotic areas of the pygidium are characteristic in the newer forms, gradually becoming indistinguishable as sclerotization spreads over the entire pygidium. These areas can be readily homologized with those of the second stage. The remaining segments of the body can be detected in newly molted individuals, but are less distinct than in the immature instars.

#### SETAE

On the anterior part of the head are 5 setae which are apparently homologous with the border head setae of the preceding stages. They are rather constant in presence, comparatively so in size, and less so in exact position. In only 2 out of the 64 groups examined were any setae absent. On the dextron of 2 individuals the most anterior seta of the group was missing, but an extra posterior seta was present on one side in 3 specimens and on both sides in 1 specimen.

The caudal head seta is absent in this stage.

The mesal seta of the prothorax and the 2 lateral mesal setae of the preceding stage are present.

The marginal setae occur essentially as in the preceding stage. The ventral marginal setae of the abdomen occur practically on the dorsal surface. The ventral setae are always cephalad of the dorsal ones. The relation of the setae to the neighboring plates is noteworthy. Typically 2 plates occur between the pairs on abdominal segments 2 to 8, and 1 plate between the setae of each pair on segments 2 to 7, inclusive. This is, however, by no means a fixed condition. No plate ever occurs between the setae of the pairs on the eighth and ninth segments, and only 1 plate between these 2 pairs. A single seta, the dorsal one, which is never missing, is borne by the first segment. Of nearly 800 segments examined, 21 showed 1 marginal seta absent and in 4 cases both were absent.

The setae (excluding the ventral abdominal marginal setae) may be segregated into several groups on the basis of the diameter, in microns, of their calyces, as follows: With diameter 4.2, fifth, sixth, and seventh abdominal marginal; with diameter 4.0, the four anterior border head and the eighth abdominal marginal; with diameter 3.6, cephalolateral prothoracic marginal and the first to fourth, inclusive, abdominal marginal; with diameter 3.2, posterior border head and caudomesal prothoracic marginal; with diameter 2.8, mesal, lateral mesal, and ninth abdominal marginal.

EYE

The only structure observed that might be taken for the eye was a prominent, well-sclerotized, rounded tubercle, which occurs cephalolaterad of the anterior spiracle near the dorsal margin of the body. Berlese (*1*, *v. 4*) indicates the presence of an eye, even to showing the optic nerve leading to it, in a related species. Yet the writer considers that here this tubercular structure might not be an eye, for reasons given below. It appears to be distinctly more caudally situated than what is taken to be the eye in other stages of this species, occurring near the first pair of marginal setae cephalad of the posterior section of the mesothorax, and in some specimens even as far caudad as one of these setae and may be almost touching one of them. If this pair of setae is a continuation cephalad of the series of marginal setae, then one or both of them may be expected to occur either on the anterior section of the mesothorax or on the prothorax. It hardly seems likely that both of these segments may be reduced nearly to the vanishing point in the vicinity of the tubercle. Also the eye, though pronounced in the first-stage female, appears to be vestigial in the second stage, but the tubercle is large and strongly developed in the adult. Morever, in other species of *Parlatoria* (eight examined) no structure that might be clearly taken for the eye was discernible in the adult female, though in this stage of one species (*P. ziziphus* Lucas) occurs a structure that probably has no relation to the eye but gives evidence, as will be indicated in the following section, of being homologous with the tubercle in *P. blanchardi*. Whether or not the tubercle under discussion is an eye can probably best be settled by tracing the optic nerve, a task not possible with the writer's material.

PORES

In other species of *Parlatoria* typically 1 to 3 or 4 raised pores occur on the ventrolateral surface of the body cephalolaterad of the anterior spiracle and apparently on the thorax. These pores vary considerably in location, but in no case was one noted definitely on the dorsal surface. Usually the rim around the external opening of a pore is very large and heavily sclerotic, as compared with the remainder of the pore. In general aspect a rim resembles the tubercle mentioned in the preceding section, suggesting that the latter might possibly be homologous with these raised pores by a small modification in position from the ventral to the dorsal margin, and in structure through the disappearance of all parts of a pore except the rim. In the adult female of *Parlatoria ziziphus*, as well as in that of *P. blanchardi*, the raised type of pore was not seen cephalad of the anterior spiracle, but in *P. ziziphus* laterad of the anterior spiracle on the margin of the body occurs a prominent, rounded knob, which may be sclerotic distally but membranous basally. This knob may or may not bear a seta, apparently one of the pairs homologous with the pair occurring near the tubercle in *P. blanchardi*. If this is so, then the latter would seem to be homologous with at least part of the knob. Until a better understanding of this tubercle is obtained, it is considered simply as an undetermined sclerite (*usc*). Close observation of the tubercle will usually reveal

a faint differential area (*da*) in it. The tubercle ranges from 12 to 18$\mu$ in diameter and from 10 to 12$\mu$ in height. It was present in all but 2 individuals, being absent from both sides in 1 specimen and from the sinistron in another. No more than 1 of these structures occurred on a side in the 32 individuals studied in detail, but among some other specimens 1 possessed on one side 2 well-developed and well-separated tubercles.

No pores of any kind were definitely recognized on the thorax of the 32 specimens studied in detail, but it is likely that one or more very minute, invaginated surface pores may have been present, for such appeared to be the case in some other specimens.

Two kinds of marginal pores are distinguished on the abdomen, primary pores and secondary pores (fig. 4, *S*, *prp*, *sep*). The primary pores, or the pores considered homologous to those similarly situated in the second-stage female, are apparently constant in occurrence. The first segment lacks 1 pore; their presence on the remaining segments agrees with that in the preceding stage. Those on segments 2 and 3 may vary a little in position, and usually are situated within the margin; those on the other segments are practically fixed in position and occur characteristically at the head of certain definite incisions. The secondary pores, or the extra ones found in this stage, are generally located somewhat within the margin, except on the sixth and ninth segments. On the 32 individuals studied, anywhere from 0 to 5 of these secondary pores occurred on any one segment from the second to the sixth; on the seventh and eighth there were 0, 1, or 2. In a special count of 1,040 margins of specimens from all 4 host palms the range in number of primary and secondary pores on each side of the body was from 12 to 39, and the average 25.1.

The structure of the marginal pores of this stage is essentially like that of those of the second stage, and here again they gradually increase in size posteriorward, with an accompanying increase in sclerotization of the rings about the external openings. There is little increase in size of the pores of this stage over those of the preceding stage. The pores of the last segment or so generally appear larger, with hardly any more sclerotization about the rings, but with broader tubes and bars; and the parts of the pores may vary somewhat in proportions.

Within the pore opening a black line (*la*) is frequently seen (fig. 4, *L*, *M*). Hoke (*5*) states that the clear area about the line represents a membrane stretched across the opening, and that the black line itself is a slit in the membrane, the actual opening into the pore. Sometimes this slit cannot be located, either open or closed (fig. 4, *I*, *J*). Occasionally, with a pore in just the right position, by racking the fine adjustment of the microscope, the slit can be made apparently to move from the opening a distance down the tube. Furthermore, the slit does not always occur in the center of the opening, and it can be made to move across the ring by racking the microscope either up or down. These facts make it almost conclusive that the slit (*la*) is simply the line of apposition of the sides of the tube when it is in a collapsed condition, and that when the slit cannot be found the tube either is not collapsed or is curved so that a sharp line cannot be detected. Usually the pores, wherever they occur on the body (of

this and other stages also), are in a collapsed condition in prepared material, and the black lines are generally distinct.

In this stage the mesal pores are scattered rather promiscuously over the segments of the abdomen, the arrangement shown in the figure being typical. The range in number on a side is from 4 to 18. The number on different sides of the meson of a single individual may vary as greatly as between individuals. On all segments except the sixth abdominal segment these pores are small. Nearly all those on the sixth segment were of medium size, the few exceptions noted being small. The following is a summary of the numbers of these pores found in the 32 individuals, those on each side of the body being counted separately: First abdominal segment, range 0 to 3, average, when present, 1.5, wholly lacking in 75 percent of cases; second abdominal segment, range 0 to 4, average, when present, 2.2, wholly lacking in 23 percent of cases; third abdominal segment, range 1 to 6, average 2.9; fourth abdominal segment, range 0 to 5, average, when present, 2.55, lacking in a single case; fifth abdominal segment, range 1 to 4, average 1.94; sixth abdominal segment, range 1 to 2, average, when present, 1.2, lacking in only 6 percent of the cases; total number present on one side of body 4 to 18, average 10.6.

The marginal raised pores are essentially like those of the preceding stage, in both structure and size. In this stage the characteristic number is 21, as compared with 18 in the preceding one, owing to the increase in number of plates, outside of which a pore is never found. Plates were frequently absent on the more anterior abdominal segments, which meant that the accompanying pores were absent as well.

#### PLATES

The plates are similar to those of the second stage in structure and contour. On abdominal segments 2, 3, and 4 they are subtriangular and without teeth, but they may vary considerably in size. The anterior plate of abdominal segment 4 is characteristically long. The plates on abdominal segment 5 are decidedly variable in outline, but on the whole broad and toothed. Those of abdominal segment 6 are predominantly broad and toothed also, and the anterior one of this segment is comparatively long. Occasionally a plate on abdominal segment 5 or 6 was much reduced in size, as in the second stage. The pore accompanying the plate was present unless the plate was actually rudimentary. The remaining 6 plates are always long, narrow, and toothed. Abdominal segments 2 to 7, inclusive, bear 3 plates each; segment 8, 2; and segment 9, 1 (fig. 4, *S*). No plates were ever absent from the pygidium, i. e., on segments 6 to 9, inclusive, but on any other segments 1 was commonly missing, and occasionally 2, while even 3 were lacking in 2 cases. In both of these cases the plates were missing on the sinistron of the third abdominal segment. From 2 to 3 extra plates were sometimes found on each margin of the second abdominal segment, and 1 extra plate sometimes on one or both margins of the fourth abdominal segment.

The total number of abdominal plates present on one side of any of the 32 specimens was found to range from 14 to 25, with an average of 20.

The teeth of the plates are essentially the same in number, size, and position as in the second stage.

#### LOBES

The first, second, and third lobes average very slightly larger than in the second stage. The contours are essentially the same, except that the third lobes are more frequently notched on the lateral sides. In many of the 32 individuals it was found that this notch either was lacking or was indistinct or replaced by three smaller notches.

The fourth lobe is considerably more rudimentary in this stage than in the preceding one. In more than half of the 64 cases in the 32 specimens this lobe was lacking or rudimentary or small and membranous and obscurely defined. In other specimens it ranged from being only faintly sclerotic along its distal margin to being apparently capable of definition and as large as 5 by 5$\mu$. The apical margin in these larger examples was often toothed, the number of teeth ranging from 2 to 8.

#### ANUS

The anus is essentially in the same location as in the second stage. It is, however, farther removed from the distal border of the median lobe, averaging for the 32 specimens 103$\mu$, with a range of from 85 to 115$\mu$ The diameter averaged 14$\mu$. The heavily sclerotic square area of the second stage, immediately cephalad of the anus, is also present in this stage.

### VENTRAL ASPECT OF THE BODY

#### BODY SEGMENTS

The parts are essentially like those of the second-stage female, except that the sutures are less distinct.

#### ANTENNA

The antenna is essentially the same as that of the preceding stage, but is slightly larger, averaging 8$\mu$ in length and width. The fleshy seta is uniformly about 18$\mu$ long.

#### SETAE

A mesal head seta reappears in this stage. The two mesal head setae are more nearly constant than the one of the second stage.

A mesal seta, apparently not present in the preceding stage, occurs here immediately caudad of the head skeleton. There is here, as in the preceding stage, a pair of mesal setae on the mesothorax. There is also an additional mesal seta on each of abdominal segments 3 to 7, inclusive. They occur characteristically as shown. Three specimens lacked setae homologous with the ones of the second stage, while in 32 cases out of 640 the new setae were absent in this stage. It happened that the specimen figured did not possess one of the new setae on the dextron of the third and fifth abdominal segments.

The thoracic marginal setae occur similarly as in the preceding stage except for some variation in position. The two anterior pairs

are spaced typically about 35$\mu$ apart, and the posterior pair about 18$\mu$ apart. Frequent variation, however, is shown in this particular. The ventral marginal seta of the posterior section of the metathorax is missing here, as in the second stage.

An increase in submarginal setae takes place on the thorax, there being generally 2 and sometimes 3 on the mesoprothorax, 3 on the posterior section of the mesothorax, and 1 on each of the 2 sections of the metathorax. What are considered to be the new setae are so labeled (*sss*) in the figure. All the submarginal setae are characteristically small, except the 3 most lateral ones of the mesoprothorax, which are of moderate size. A pair of submarginal setae appear to be associated with each pair of marginal setae on the thoracic segments. There is also a pair on the posterior section of the metathorax, which may be considered as associated with the dorsal marginal seta of the first abdominal segment. These paired setae of the submarginal series may be called the anterior and posterior submarginal setae (*ass*, *pss*). This leaves several setae near the anterior spiracle in a separate grouping, the spiracular submarginal setae (*sps*). The pairs of submarginal setae, as well as all those posterior to these, are relatively constant in position, but those of the spiracular group are rather variable, and usually one or more are at a moderate distance from the spiracle. The anterior and posterior submarginal setae on the prothorax and on the posterior section of the metathorax were each missing once, and the anterior one of the mesothorax twice; none of the others was ever absent. In the spiracular group a moderate-sized one was present in all but 5 instances, while 3 small setae were present in 12 instances, 4 in 45 instances, and 5 in 7 instances out of the total of 64. The submarginal setae of the abdominal segments are similar in number and position to those of the second stage. On the abdomen 11 submarginal setae out of a possible 384 were missing. The setae on the ventral surface (including ventral abdominal marginal) may be arranged in several groups on the basis of the diameter, in microns, of the calyx cup, as follows: With diameter 4.0, mesoprothoracic marginal; with diameter 3.6, mesothoracic marginal; with diameter 3.2, metathoracic marginal, second to seventh, inclusive, abdominal marginal, and mesoprothoracic submarginal paired; with diameter 2.8, mesal head, eighth abdominal marginal, mesoprothoracic medium-sized spiracular and mesothoracic submarginal; with diameter 2.3, mesal setae and all remaining submarginal and spiracular; with diameter 1.6, ninth abdominal marginal.

### PORES

There are usually 1 or 2 small pores on the mesoprothorax, both laterad in position but somewhat away from the border. A few scattered pores are present near the border on the mesothorax, which are on the average slightly larger than the mesoprothoracic pores. On both sections of the metathorax, distinctly near the border, is a rather closely bunched group of pores, which are considered to be a combination of the marginal and submarginal pores of the preceding stage. The two types cannot be separated on any of these segments. It has already been mentioned that the marginal pores of the abdomen gradually decrease in size anteriorward. This decrease continues until the pores on the mesoprothorax resemble any of the small

pores of the body, such as the dorsal mesal pores (*mbp*) of the abdomen. For convenience all pores discussed above on the ventral surface will be called simply the submarginal pores. From a tabulation of the numbers of these ventral submarginal pores, based on the 32 individuals under discussion, the following summary has been drawn: Mesoprothoracic pores, range 0 to 2, lacking in 37 percent of cases considered, average, when present, 1.5; mesothoracic, range 1 to 14, average 6; anterior section of metathoracic, range 5 to 24, average 12; posterior section of metathorax, range 1 to 14, average 6.6.

The small ventral mesal pore (*vmep*) of the preceding stage laterad of the head skeleton is present in this one, too.

The fourth and fifth abdominal segments may each bear a small pore in the neighborhood of the mesal setae. The sixth and seventh abdominal segments usually have 1 or 2 similar small pores each, rather posterior in position. In 5 cases there was also a pore on the eighth segment. None of these abdominal pores were present in the preceding stages. They are called the posterior body pores (*pbp*). A summary of a tabulation of the number and occurrence of these posterior body pores on each side of the body in the 32 individuals studied gave the following results for the fourth to eighth abdominal segments, inclusive: Fourth, range 0 to 1, lacking in 45 percent of cases; fifth, range 0 to 1, lacking in 45 percent of cases; sixth, range 0 to 3, average, when present, 1.4, lacking in 14 percent of cases; seventh, range 0 to 2, average, when present, 1.3, lacking in only 3 percent of cases; eighth, range 0 to 1, lacking in 92 percent of cases.

The raised pores are in structure essentially like those of the second stage, and similarly placed. The mesoprothorax never showed a raised pore; it will be remembered that in but a single instance did one occur there in the preceding stage. The mesothorax rarely has a raised pore, in contrast to the 1, 2, or 3 which were the rule in the preceding stage. The anterior section of the metathorax, on the other hand, has them in nearly equal numbers in the two stages, but the posterior section of the metathorax possesses generally from 1 to 4, whereas in the preceding stage no more than 1 was ever found on this segment. The numbers of raised submarginal pores, counting those from each side of the body separately, in the 32 specimens studied, were as follows: Mesothorax, range 0 to 3, average, when present, 1.3, lacking in 90 percent of cases; anterior section of the metathorax, range 0 to 3, average, when present, 1.6, lacking in 30 percent of cases; posterior section of the metathorax, range 0 to 4, average, when present, 1.9, lacking in 16 percent of cases.

The spiracerores are similar in all respects, including size, to those of the second stage. In a count of 2,378 groups on specimens from all 4 host palms the range in number of pores in each group was from 0 to 5, and the average 2.1. The number of openings in each pore was usually 5, sometimes 4, occasionally only 3, and in one instance 7.

Of the same type of pore, and essentially like the spiracerores, are two groups occurring on each side of the meson on the pygidium, near the vagina, probably on the sixth abdominal segment. These are the "genacerores" (*gc*) of MacGillivray (*8*); they are commonly

termed the "circumgenital" or "paragenital" pores, but the writer prefers the more technical word, both because they are of a different type from the usual pores and because this term clearly distinguishes them from the posterior body pores which also occur near the genital opening. The genacerores are larger than the spiracerores, being almost uniformly 5.5$\mu$ in diameter; also they are somewhat more strongly sclerotic. A part of the outer ring of this type of pore can be seen in the genacerores better than in the spiracerores. A side view shows the ring to be distinctly raised above the pore openings, the parts on each side, in focus, appearing as sharp curving lines (fig. 4, *N*). By focusing either up or down, the curving lines can be made to extend over and meet, forming a dome over the openings. A casual glance suggests that these are covered by a dome-shaped membrane, but a careful examination shows that what is seen is merely the edge of the ring on the more elevated side of the pore. (The openings are indicated by the dotted line in the figure.) A perfect side view would, of course, not show the dome. Occasionally an individual is found with 1 and even 2 genacerores on the median line, clearly separated from the others. The pores of the groups are occasionally so scattered or so bunched together that it is difficult, if not impossible, to separate the groups.

An enumeration of the genacerores included in each group in 1,091 specimens selected at random from the four host palms gave a range of from 1 to 14 and an average of 8.1 for each anterior group, and a range of from 0 to 10 and an average of 5.8 for each posterior group.

#### LEGS

The legs are apparently absent.

#### SPIRACLES

Both pairs of spiraculariae are directed laterad. The anterior pair were on the average slightly shorter, but a little wider, than the posterior pair. The range in length of the former was from 21 to 30$\mu$, with an average length of 27$\mu$; of the latter from 27 to 36$\mu$, with an average of 28$\mu$. The spiracularia of the former averaged in width 18$\mu$; of the latter, 17$\mu$. The spiracle itself was approximately 9$\mu$ in diameter for both pairs.

#### VAGINA

Before egg deposition begins the vagina is always shaped as shown in figure 4, *A*. The walls appear to be rather thick, the actual free tube being the area limited by the mesal dotted line. At the anterior end is a characteristic and distinct sclerotic area (fig. 4, *Y*, *vcha*). When egg deposition begins, the vagina is either ruptured to a shapeless piece or is evaginated (fig. 4, *Y*), sometimes both. In length the vagina averaged, for 50 specimens, 77$\mu$ from the external opening to the anterior sclerotic area, the range being from 68 to 90$\mu$. On the same number of specimens the vulva (*vu*) averaged 20$\mu$ cephalad of the anus, the range being from 11 to 36$\mu$. The vulva is located probably between the seventh and the eighth abdominal segments.

#### ROSTRALIS

In length the rostralis averages about the same in proportion to the length of the body as in the second stage. From a tabulation of the lengths of the body in relation to the lengths of the corresponding rostralis it is evident that the two are not directly proportional. In 25 specimens examined in this respect the general average ratio between length of body and length of rostralis was 1 to 6.25; the lowest ratio noted was 1 to 4.6, the highest 1 to 9.3; the average length of the rostralis in these specimens was 4.18 mm, the range from 3.07 to 4.92 mm; the average length of the body was 0.67 mm, the range from 0.49 to 0.84 mm.

The position of the rostralis within the body is irregular in prepared specimens, but the end loop is characteristic in shape, and averaged 59$\mu$ long by 18$\mu$ wide.

### SECOND-STAGE MALE

Twenty-four individuals, 8 each from the date and Canary Island palms and 4 each from the Washingtonia and doum palms, were studied. The newly molted individuals (fig. 5, *A*) average very slightly smaller than the second-stage females, although the sizes overlap freely. The average dimensions for 40 newly molted individuals of this stage were 0.36 mm long and 0.28 mm wide: the length range was from 0.35 to 0.37 mm, the width range from 0.27 to 0.29 mm. When newly molted the two sexes cannot be distinguished by contour, but in time the body of the male becomes elongate-oval, in contrast to the more roundly oval body of the female. Seventeen fully matured examples of this stage just ready to molt showed an average length of 0.61 mm and an average width of 0.33 mm.

#### DORSAL ASPECT OF THE BODY

##### BODY SEGMENTS

The segments are similar to those of the second-stage female.

##### SETAE

The border head setae are similar in number and size, and practically so in occurrence, to those of the second-stage female. The only variation from the normal 4 large ones and 1 medium one was in 1 specimen that possessed an extra large cephalic seta on the dextron.

The mesal head setae of the first stage are retained in this stage. As a rule they are slightly smaller than the larger border head setae. In no instance was one missing.

The caudal head seta of the first stage and of the second-stage female is also present here in moderate size. There is an additional seta in the series, a very small one generally, caudolaterad of the other. The primary seta was never missing, but the new seta was missing four times from one side and twice from both sides, in the 24 individuals studied.

The thoracic and abdominal mesal setae of the first stage are all retained, also the prothoracic mesal seta of the second-stage female.

FIGURE 5.—Second-stage male: *A*, Body (dorsal surface at right of observer); *B*, prothoracic leg; *C*, mesothoracic leg; *D*, metathoracic leg; *E*, marginal pore of eighth abdominal segment; *F*, marginal pore of first abdominal segment; *G*, marginal pore of metathorax; *H*, marginal pore of mesoprothorax; *I*, *J*, mesal body pores of sixth abdominal segment; *K*, mesal body pore; *L*, ventral mesal pore of mesoprothorax; *M*, marginal raised pore of ninth abdominal segment; *N*, posterior marginal raised pore of fourth abdominal segment; *O*, submarginal raised pore of metathorax. *A*, ×365; *B-O*, ×1,040.

33918°—34——5

All these setae are small, their calyces approximately 1.9$\mu$ in diameter. The position of these setae is characteristic, similar to that in the first stage, except that the second abdominal one is usually situated distinctly mesad of the neighboring ones. The posterior prothoracic one was absent once from the sinistron.

The lateral mesal and marginal setae are similar to those of the second-stage female in number, position, size, and occurrence. The caudal one of the marginal series on the prothorax was absent once on the sinistron of one specimen.

EYE

The eye is nearly always recognized, usually distinct and rather well developed, but occasionally it appears to be hardly more than vestigial.

PORES

The marginal pores are essentially like those of the second-stage female, except that characteristically an extra pore may be present on one or more of the following segments: Mesothorax, metathorax, and first and second abdominal segments. These extra pores are included in the secondary pore series. The secondary pores on the first and second abdominal segments may be reduced in size or absent; also on the fourth and fifth abdominal segments they may be absent. The single marginal pores on the mesothorax and the metathorax were considered as belonging to the secondary pore series because of their positions and generally stouter proportions than those of the neighboring pores of this surface.

The pores corresponding to the mesal body pores of the second-stage female are present in this stage in greater numbers, mainly toward the meson, and the posterior ones average larger in size. There is, however, no fundamental difference between them. A distinctive lateral row of the pores occurs here, as in the second-stage female, with the addition of 1 or 2 pores near the margin on the metathorax. A typical example of the number and position of pores on the segments is shown for the individual figured. The sizes, in microns, of the mesal body pores on the abdomens of the 24 specimens, together with a comparison of the sizes of these pores among themselves, have been summarized as follows: First abdominal segment, range 1 to 5, average 3.14, with 83.5 percent of the 151 individual pores small, 14.5 percent medium, and 2 percent large medium; second abdominal segment, range 1 to 4, average 3.0, with all the pores small; third abdominal segment, range 1 to 3, average 2.9, with 84 percent of the 137 pores small, 9.5 percent medium, and 6.5 large medium; fourth abdominal segment, range 1 to 4, average 2.3, with 60 percent of the 112 pores small, 12.5 percent medium, 23 percent large medium, and 4.5 percent large; fifth abdominal segment, range 1 to 3, average 2.0, with 42 percent of the 95 pores small, 10.5 percent medium, 33 percent large medium, and 14.5 percent large; sixth abdominal segment, range 1 to 3, average 2.0, with 9.5 percent of the 95 pores small, 33 percent medium, 9.5 percent large medium, and 48 percent large.

The marginal raised pores are in all essentials similar to the corresponding ones of the second-stage female, with approximately the same variations of occurrence.

#### PLATES, LOBES, AND ANUS

These structures also are similar in every noticeable particular, including occurrence, to those in the second-stage female.

### VENTRAL ASPECT OF THE BODY

#### BODY SEGMENTS

The segmentation of the body appears to be similar in all respects to that of the second-stage female.

#### ANTENNA

The antenna resembles that of the second-stage female except that its largest projection is somewhat more elongate.

#### SETAE

The three mesal head setae of the first stage are all present. The mesal and the marginal setae are similar to those of the second-stage female. The ventral marginal seta of the eighth abdominal segment is, however, distinctly smaller than the one in the second-stage female. The submarginal setae are similar to those of the second-stage female, except that the eighth abdominal one is retained and there is occasionally an extra one on the mesoprothorax and one on the posterior section of the mesothorax. All the setae of this surface, excluding the extra ones near the margin of the mesothorax, are constant in occurrence.

#### PORES

The marginal pores on the posterior section of the mesothorax and the anterior section of the metathorax are difficult to distinguish from the submarginal pores. From their position it is interpreted that the caudal one on each of these segments is the true marginal and primary pore. As in the second-stage female, the caudal pore of the mesoprothorax is distinctly larger than the more cephalic ones, and is considered to be a marginal pore. As compared with the second-stage female, an extra submarginal pore frequently occurs on the posterior section of the mesothorax and the anterior section of the metathorax. The submarginal pores are slightly larger and more sclerotic than those of the second-stage female. A small submarginal pore was occasionally observed on the head, usually mesad of the antenna. A count of the marginal and submarginal pores of both surfaces, up to and including the marginal pore of the mesoprothorax but not the little submarginal pores of this segment, on 254 specimens from all 4 host palms, showed a range of from 18 to 27 pores, and an average of 21.2 pores, on each side of the body.

The mesal pores (*vmep*) of the thorax occur as in the second-stage female, except that the one on the posterior section of the mesothorax appears to be frequently absent.

A single small pore is always found on the submargin of each of the fourth to seventh abdominal segments, and one is usually present near the meson of each of the second to sixth abdominal segments. All these may be known as the posterior body pores (*pbp*). None, it

will be remembered, appeared in the second-stage female, but, as has been mentioned, the adult female does have some pores on the posterior part of the abdomen similar in every respect to the pores here.

In contrast to the single occurrence of a raised pore on the mesoprothorax in the second-stage female, this pore was observed 13 times in this stage. Also 2 raised pores on the posterior section of the metathorax were observed 4 times in this stage, but not once in the second-stage female.

The spiraceroris is essentially like that of the second-stage female. From an examination of 218 specimens, considering each side independently, 2 pores occurred once, no pores 4 times, and a single pore in all the remaining cases.

#### LEGS

The legs are in most instances distinct on all three segments as very small protuberances, which are generally somewhat sclerotic at the tips. They are frequently plainly separated into segments (fig. 5, *B*, *C*). Though always considered as present, they are undoubtedly in a vestigial condition, but not so much so as in the second-stage female. The dotted areas about the legs in figure 5, *A*, represent the developing third-stage legs, which do not actually appear in an individual as young as the one represented. This also holds true for the dotted area about the antenna, representing the developing third-stage antenna. These areas are placed here as a matter of convenience, being in fact the only extraneous structures shown on the figure.

#### SPIRACLES

The spiracles are essentially like those of the second-stage female.

#### ROSTRALIS

The rostralis does not differ in any noticeable particular from that of the second-stage female, and is not shown in the figure.

### THIRD-STAGE MALE

Seven specimens, 4 from the date palm, 2 from the doum palm, and 1 from the Canary Island palm, were studied. The body is elongate-oval (fig. 6, *A*), and the average length and width of 6 of the specimens was 0.59 and 0.29 mm, respectively. The figure shows the typical condition of the various structures.

All pores, plates, and lobes, as well as the eye and the pygidium, are absent. The spiracles show no unusual features, and will not be discussed.

#### DORSAL ASPECT OF THE BODY

##### BODY SEGMENTS

A part of the suture (*prs*) between the head and the prothorax can be detected only with difficulty. All the other segments are distinct except the ninth abdominal one, which is much reduced but apparently can be at least partially differentiated by an indentation in the body margin.

SETAE

Four setae along the submargin of the head are considered to be the border head setae. The 2 anterior ones are comparatively large

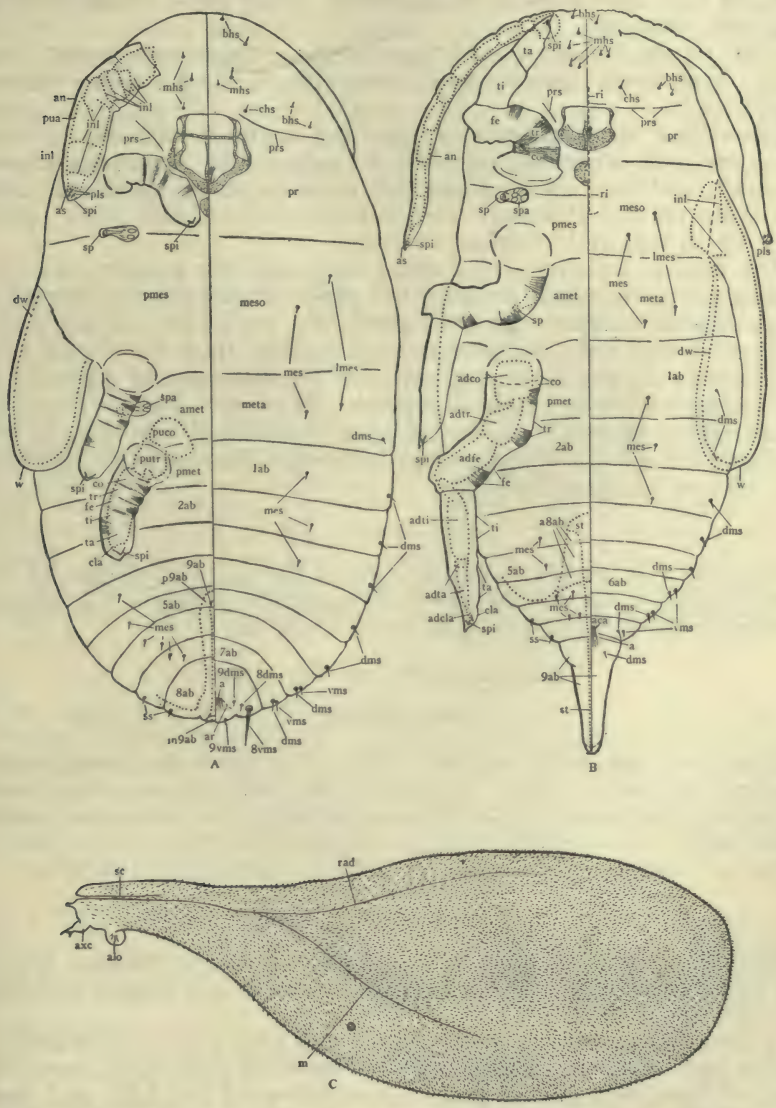


FIGURE 6.—*A*, Third-stage male (dorsal surface at right of observer), × 155; *B*, fourth-stage male (dorsal surface at right of observer), × 135; *C*, adult wing, × 140.

and always present; the 2 posterior ones are always small, and 1 of them was missing in 3 instances.

The large and small setae close together near the meson of the head are interpreted as the mesal head setae. Each one may be either large or small; neither was ever missing.

The seta cephalolaterad of the anterior margin of the endoskeleton is considered to be the caudal head seta. It is variable in size, and was absent 4 times out of a possible 14.

The mesal setae are present on the mesothorax, the metathorax, and the first three abdominal segments. They are constant in presence and position.

Both lateral mesal setae of the preceding stages are present here. They were never missing and were always in the same relative positions.

The dorsal marginal setae are limited to the metathorax and the abdomen, one occurring on each segment. The metathoracic seta is small, and was absent from both sides on four specimens. All the setae on the abdomen were always present, and were nearly uniform in size and position.

The ventral marginal setae occur very near the margin, and it is usually a question as to whether the anterior ones are on the ventral or the dorsal surface. In the figure they are shown on the dorsal surface. They are usually somewhat smaller than the dorsal setae and, except on the ninth segment, are always situated cephalad of the latter. With a single exception, they were always found on abdominal segments 6 to 9; one specimen lacked one seta on the sinistron of the sixth abdominal segment. The eighth abdominal seta (*8vms*) is unusually large.

#### ANUS

The anus is located about 15$\mu$ from the caudal margin of the body, and is 9$\mu$ in diameter. It is narrowly sclerotic. A characteristic ridge (*ar*) curves caudolaterad from it.

### VENTRAL ASPECT OF THE BODY

#### BODY SEGMENT

The ninth abdominal segment (*9ab*) over much its greater extent is very long and narrow. All except the very base is invaginated, represented in the figure by the mesal dotted area. The outer dotted area (*p9ab*) represents the ninth abdominal segment of the fourth instar in a similarly invaginated condition, developing around it.

#### SETAE

The 3 mesal head setae were present in every instance but 3; the cephalic one was missing from both sides in 1 specimen and from one side in another.

A mesal seta occurred on the fourth and fifth abdominal segments, and a pair of them on the sixth and seventh abdominal segments. One of these was absent from the sinistron of the fifth and sixth abdominal segments of a single specimen. One specimen showed 2 setae on a side on all 4 of these segments and, in addition, a very small seta on each side of the third segment. Another specimen showed 2 setae on the dextral side of the fourth abdominal segment, and a third specimen had 2 on the dextron of the fourth and fifth abdominal segments. A ventral submarginal seta always occurred on the eighth abdominal segment, and was present in 7 instances on the seventh and in 2 on the sixth.

In this stage the measurements of the setae from both surfaces have been considered together. They may be grouped as follows, according to the diameters, in microns, of their calyces: With diameter 4.7, the eighth abdominal ventral marginal; with diameter 2.4, two cephalic border head, outer dorsal mesal head, and first to seventh, inclusive, abdominal dorsal marginal; with diameter 2.1, inner dorsal mesal head, caudal head, lateral mesal, dorsal mesal of thorax, dorsal marginal of metathorax, and eighth abdominal dorsal marginal, remaining ventral abdominal marginal, and the ventral mesal head; with diameter 1.9, two posterior border head, ventral mesal of abdomen, submarginal; with diameter 1.6, ninth abdominal dorsal marginal; with diameter 1.4, antennal.

#### ANTENNA

The antenna develops within the body of the second-stage male (fig. 5, *A*) in a telescoped condition, the cross dots in the figure representing the lines of the major invaginations. Three segments of the antenna are generally recognized, two short basal ones directed caudolaterad and a long distal segment bent more caudad. The antenna is typically about 360$\mu$ long by 160$\mu$ wide. It possesses no noticeable structures except near the tip, where it generally bears a very small seta (*as*), a short spinelike projection (*spi*), and 2 or 3 small clear areas (*pls*) which are probably sensory in nature. In the older individuals the fourth-stage antenna is visible within as a partially invaginated structure, owing to its much greater length. It is in a decidedly crumpled-up condition near the bend, on account of its crowded quarters, and folds are present in it nearer the tip.

#### LEGS

The segments are in part distinctly sclerotic. A characteristic spinelike projection is present near the tip of each leg. The developing fourth-stage leg is plainly visible in the older individuals. It is so much longer than the third-stage leg that the coxa appears to have been crowded entirely out of the leg into the body proper.

#### WING PADS

The wing pads (*w*), when present, arise on the lateral margins of this surface, typically as shown, and are always well developed. From an examination of 49 males of this stage obtained from all the host palms considered, the wing pads were absent in 55 percent of the specimens.

### FOURTH-STAGE MALE

Nine specimens, 4 each from the date and Canary Island palms and 1 from the doum palm, were studied. The body is approximately the same size as in the third stage, though it averages somewhat longer from tip to tip, owing to the extended position of the ninth abdominal segment (fig. 6, *B*). The average length and width of the body, for the specimens studied, were 0.72 and 0.26 mm, respectively.

As in the third-stage male, all pores, plates, and lobes, as well as the eyes and the pygidium, are absent. The spiracles are well developed but appear to possess no features worthy of discussion.

### DORSAL ASPECT OF THE BODY

#### BODY SEGMENTS

The extended caudal piece is readily seen to be simply the ninth abdominal segment. The characteristic segmentation is as figured. A distinct ridge (*ri*) extends along the meson from near the posterior margin of the head to the middle of the mesothorax. In emerging, the adult splits the skin along the meson from the cephalic border just to the caudal end of this ridge, which evidently has something to do with the molting process. The lateral split takes place along the submargin of the head, between the posterior border head setae, as far as the prothorax. The position and extent of the splitting of the third-stage skin correspond to those of the fourth.

#### SETAE

All the setae of this surface are essentially like those of the third stage in size, position, and occurrence, except that the marginal metathoracic one was not observed and the eighth ventral abdominal marginal seta is similar in size to the other marginal setae in this stage; also the cephalic border head seta appears to be situated nearly, if not quite, on the ventral surface.

#### WING PADS

The wing pads arise from the submargin of the mesothorax on this surface. They fold over onto the ventral aspect, about half of the wing pad occurring on each surface, typically as represented. The adult wing developing within the fourth-stage one, being somewhat longer than the latter, is a little folded near the base, as indicated by the short dotted lines. When present the wing pads always appear well developed. In this stage they were absent in 40 percent of 99 specimens examined from all the host palms.

#### ANUS

This structure is apparently situated on the ninth abdominal segment, just caudad of the anterior margin. Its distance from the caudal tip of the segment averaged, for all individuals, 104$\mu$, the approximate length of the segment. The diameter of the anus averaged 12$\mu$.

### VENTRAL ASPECT OF THE BODY

#### BODY SEGMENTS

A noticeable feature of older individuals is the developing ninth abdominal segment, or the stylus (*st*), of the adult within the body. The stylus is so long that only about half of it can come within the fourth-stage projection. The base of the stylus extends cephalad nearly to the third abdominal segment of the fourth instar, and in consequence the eighth abdominal segment of the adult is forced forward to this extent.

#### SETAE

Four head setae, apparently belonging to the mesal group, are present in this stage, in contrast to the three present in all the preceding male stages. One seta was absent in a single instance. The mesal and the submarginal setae occur essentially as in the preceding stage.

#### ANTENNA

This structure averaged, for the nine specimens, 280$\mu$ long by 24$\mu$ wide. Indentations along the outer basal half are the only distinct segmental indications. In older individuals the adult antenna is plainly discernible within the fourth stage. There is sufficient room for it to develop entirely within the latter, without such folding as takes place within the third stage. A short spinelike projection always occurs at the apex of the antenna; a very small seta (*as*) and 1 or 2 small, apparently sensory structures (*pls*) are generally present also.

#### LEGS

The segmentation can be made out more readily than in the third instar. The outer margin of a leg projects characteristically about half the distance between the base and the tip. This bulging is to accommodate parts of the adult femur and tibia (*adfe*, *adti*). The legs of the fourth instar also have the short spine (*spi*) at their apices.

## ADULT MALE

Sixteen individuals, four from each palm, were studied. The average length and width of 15 individuals were 0.80 and 0.20 mm, respectively. Their size varied considerably, from one individual measuring 0.64 mm long by 0.16 mm wide, to one measuring 0.86 mm long by 0.22 mm wide. These wide variations were noted in other specimens, not only of the adult, but of the third and fourth instars as well. The specimen figured (fig. 7, *A*) represents an individual from the doum palm.

There are no pores present that can definitely be recognized as such; plates and lobes are also absent.

#### DORSAL ASPECT OF THE BODY

#### BODY SEGMENTS

A narrow sclerotic area (*cha*) extends caudolaterally across the meson of the head, and may limit its caudomesal margin. The anterior margin of this area projects some distance from the meson cephalolaterad, decreasing rapidly to a line, and then curving sharply cephalomesad near the mesal margin of the eye, producing within a distinctly raised area (*ra*) that always bears four of the head setae.

The strongly sclerotic framework covering the central part of the body is considered to embrace the mesothorax. Between the mesothorax and the sclerotic area (*cha*) and a lateral indentation, that is, in position to be the prothoracic suture (*prs*), lies the prothorax.

The sclerites of the mesothorax may be defined as follows: The praescutum (*psc*), appearing from the dorsum as a narrow, curving, strongly sclerotic band along the mesocephalic margin and a broader

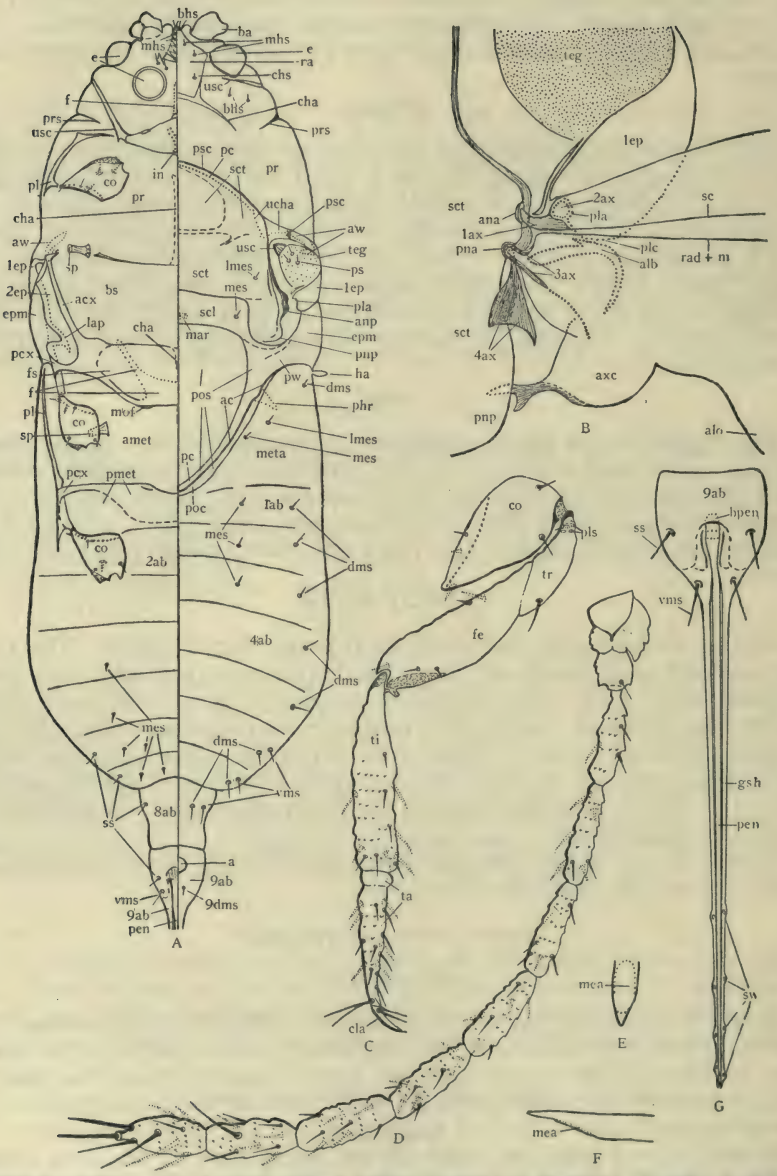


FIGURE 7.—Adult male: *A*, Body (dorsal surface at right of observer), × 195; *B*, articulation of wing, × 875; *C*, mesothoracic leg, × 350; *D*, ventral surface of antenna, × 350; *E*, ventral aspect of tip of penis, × 2,630; *F*, lateral aspect of tip of penis, × 2,630; *G*, genital armature, × 350.

extension laterally; a wide, more or less membranous area immediately caudad of the praescutum and extending to the articulation of the wing, the scutum (*sct*); a sclerotic band in the center of the framework, the scutellum (*scl*); a broad membranous area immediately caudad of the scutellum, followed by a narrower, curving, strongly sclerotic band, both parts constituting the postscutellum (*pos*). Berlese (*1, v. 4, pp. 101–102, 161*) gives the postscutellum as belonging to the metathorax.

Below the cephalic margin of the praescutum and attached to it is a sclerotic band, the precosta (*pc*).[4] Laterad of the precosta, and below the praescutum, is an undetermined sclerotic area (*ucha*) which may be inconspicuous or developed as shown in the figure. Laterad of this sclerotic area, and also below the praescutum, is a sclerotic piece, of characteristic form, which is in position to be the prealar wing process (*aw*). A differentiated area (*mar*), usually membranous, and varying to some extent in size and contour, is located on the meson of the scutellum. The strongly sclerotic caudal section of the postscutellum is divided by a distinct suture, considered to be the antecostal suture (*ac*), into an anterior part, designated the precosta (*pc*), and a posterior part, designated the postcosta (*poc*). The postscutellum extends, without any apparent interruption, onto the pleuron, but is considered to be separated from the latter by the postalar bridge (*pw*).

The metathorax is quite broad laterally, but on the meson is sharply reduced to hardly more than a line by the posterior projection of the mesothorax.

The abdomen is clearly differentiated into 9 segments. The first 7 are of the usual form, the eighth is narrowed, and the ninth is composed of a swollen base and a long, rapierlike distal portion.

### SETAE

There are 4 border head setae, as in the third and fourth stages. The 2 cephalic ones are on the cephalomesal margin, 1 on the ventral surface and 1 on the dorsal. These were never absent. The 2 posterior ones are near the caudolateral margin. One or both of these were absent in 5 instances.

The usual 2 mesal head setae and the caudal head seta are present on the raised area. The caudal head seta and a posterior seta of the mesal head pair were absent from the sinistron of 1 individual.

The mesal and lateral mesal setae are present here as in the two preceding stages. From 1 to 3 additional setae occur on the pleuron, cephalolaterad of the anterior lateral mesal seta. They are called the pleural setae (*ps*).

The marginal setae occur essentially as in the two preceding stages. The ventral marginal setae appeared to be placed on this surface, and occurred on either one side or the other, or both, on the fifth abdominal segment 12 times, and on the fourth segment 7 times, out of a possible 32.

The setae may be grouped as follows according to the approximate diameter, in microns, of their calyces: With diameter 2.4, all marginal setae on dorsum, except ninth abdominal one; with diam-

[4] Many of the terms used to describe the parts of the thorax on both the dorsum and the venter are those used by Snodgrass (*13*).

eter 2.0, all head, mesal, and lateral mesal; with diameter 1.6, ninth abdominal.

EYES

An eye is present on the dorsolateral margin, dome-shaped, and about 27$\mu$ in diameter and 22$\mu$ in thickness. The eye is never absent, though occasionally it is somewhat reduced in size.

WINGS

Targioni Tozzetti (*14*) states that this species is wingless; yet the writer has found the winged individuals to predominate. Not uncommonly, however, the wings were observed to be only partially developed. Of 186 adult males from all the host palms considered, it was found that only 25 percent were wholly wingless, 56 percent had fully developed wings, and in 19 percent the wings were present in various degrees of development, 11 percent having them less than half size. In all specimens the thoracic wing framework was fully developed.

The fully developed wing (fig. 6, *C*) is about 0.64 mm long by 0.24 mm wide, shaped typically as shown in the figure. It bears numerous spinulae scattered evenly over its surface, and has two prominent veins, which are united for most of their proximal halves. Comstock (*2, p. 290*) quotes Patch (*11*) as indicating that the anterior vein is the radius (*rad*) and the posterior one the median vein (*m*). At the base of the wing, cephalad of the coalesced veins, occurs a short, delicate line, called by Patch the subcostal vein (*sc*). A prominent lobe, the alar lobe (*alo*), occurs near the posterior proximal margin. The articulation of the wing to the thorax (fig. 7, *B*) agrees apparently with what Snodgrass (*13*) found to be the condition for the general insect wing. Two points of articulation occur on the notum, the anterior notal wing process (fig. 7, *A*, *anp*) on the lateral margin of the scutum and the posterior notal wing process (*pnp*) on the scutum and near its caudal border. These two processes are borne by membranous tissue, and considerable flexibility appears to be possible. The margin of the anterior process, however, is strongly sclerotic, this sclerotization continuing cephalad as a very narrow band. Two distinct indentations occur in the anterior process, the anterior notal wing acetabulum (*ana*) and the posterior notal wing acetabulum (*pna*). These are actually the articulating points of the anterior process. Into the former fits a curving, heavy sclerite, closely attached to the wing, the first axillary sclerite (*1ax*); into it, above, a heavy, narrow, roundly curving sclerite, the third axillary (*3ax*), which is deeply indented by a projection of the base of the wing. The third axillary appears to be joined so firmly to this projection as to seem almost a part of it. Below, the third axillary sclerite apparently rotates on the distal knob of a heavy sclerite, the fourth axillary (*4ax*), which articulates beneath the third also with the posterior wing acetabulum. The fourth axillary is broadly and concavely expanded at its base, which apparently rocks about the cephalic part of the rounding margin of the posterior notal wing process. The fourth axillary sclerite is so thickened on its mesal half that this region resembles a stout projection. From its shape and position it

probably acts in part as a brace to the backward movement of the wing. The strongest brace of the wing, however, is probably the axillary cord (*axc*), a swollen clublike projection from the posterior margin of the base of the wing. The proximal end, which is emarginate and strongly sclerotic, fits around the posterior notal process, and also appears capable of a rocking motion. The second axillary sclerite (*2ax*) is situated below the wing. It is globular and articulates proximally against the first axillary and distally against the pleural wing acetabulum (*pla*).

The wing articulates against one process on the pleuron, which is composed of two elements, the pleural wing acetabulum and the pleural wing condyle (*plc*), against which abuts a sclerotic thickening on the under surface of the wing, the alar buttress (*alb*). This is a crescent-shaped structure, convex, facing the condyle, with a special projection from its margin as the articulating surface. The sclerite bearing the pleural wing process is thought to be the anepisternum (*1ep*) of Crampton (*3*). It curves laterocephalad onto the ventral surface. A membranous piece is situated cephalad of the latter, and is in position to be the tegula (*teg*). It bears the pleural setae. An undetermined subtriangular sclerite (*usc*) borders the mesocephalic margin of the tegula. From its position and shape this sclerite appears to serve as a buttress against the forward movement of the wing, in much the same manner that the axillary cord acts as a brace against the backward movement of the wing.

The part along the body margin and connected to the postscutellum by the postalar bridge is designated the epimeron (*epm*). It is distinct from the anepisternum, and apparently possesses no wing-articulating points.

The halteris (*ha*) was present occasionally as a projection from the cephalolateral margin of the metathorax. In some individuals it was difficult to decide whether this structure was actually present or not. Except when vestigial, occurring as hardly more than slight bulgings from the body, even the smaller ones appeared in contour surprisingly like the fully developed wings, being neither threadlike nor knoblike. This structure was found to be present in only 17 percent of the 184 adult males from all the host palms examined. When the halteris was present it was always found on both sides, but there was sometimes a noticeable difference in size on the two sides. The size also varied greatly from individual to individual. The range in length was from 36$\mu$ down to 2$\mu$. The halteris possessed no distinguishable secondary structures, though prominent distal setae are borne by other species of *Parlatoria*.

#### ANUS

The anus, which is subcircular in outline, appears to be situated on the ninth abdominal segment. It is about 12$\mu$ in diameter.

### VENTRAL ASPECT OF THE BODY

#### BODY SEGMENTS

The homologies of the segments were determined mainly from the positions of the legs, spiracles, and sutures.

A delicate structure (*in*), apparently an invagination, occurs on the meson immediately cephalad of the prothoracic leg. This is considered to be the entrance to the alimentary tract. An internal projecting structure (*f*) occurs on the meson cephalad of the above-mentioned invagination. At first glance it might be thought to be a part of the alimentary tract, but it is strongly sclerotic, and is of a definite length, ending abruptly, and is interpreted as a furca of the head. The caudal margin of the head is delimited by a delicate suture extending from the invagination of the alimentary tract toward an indentation in the body margin. A narrow, undetermined sclerotic piece (*usc*) extends laterocephalad from this suture onto the dorsum of the head.

On the meson, in the suture separating the anterior from the posterior section of the mesothorax, a long sclerotic piece (*cha*) occurs. It appears to be on the surface, and for this reason is not considered to be a furca. The posterior section of the mesothorax is apparently composed of two parts, a basisternum (*bs*) and a furcisternum (*fs*). Laterally the basisternum is bounded by a narrow sclerotic piece, the precoxal bridge (*acx*). The precoxal bridge extends cephalolaterad, turns dorsad near the prealar wing process, abuts against the latter, and then, apparently, turns caudad to extend along the mesal margin of the anepisternum. It is probable that this caudal extension can be considered as no more than a differentiated part of the katepisternum (mentioned below). The furcisternum is connected with the pleuron by a bridge, the postcoxal bridge (*pcx*). It may seem questionable to call this bridge "postcoxal" when it is situated cephalad of the coxa. However, the coxa has been drawn noticeably caudad, and in consequence has thrown the neighboring parts out of their usual alinement. Shepard (*12*) indicates the lateral extension of the furcisternum in some typical Lepidoptera as being cephalad of the coxa. Between the basisternum and the furcisternum a small sclerotic area (*cha*) is located, As it also appears to be on the surface, it is not considered to be a furca. Along the caudal margin of the furcisternum a prominent pronged furca having a broad base arises.

As herein interpreted and indicated, the anepisternum extends onto the venter as a narrow curving piece that joins the caudal extension of the precoxal bridge. Posterior to the anepisternum, and plainly separated from it, are two sclerites. Between these, along a distinct suture, is a prominent apodeme (*lap*). The mesal sclerite (*2ep*) appears to be homologous to the katepisternum of Crampton; the lateral sclerite is a continuation of the epimeron of the dorsal surface. No definite division of the epimeron could be distinguished. Below the line of the invagination of the apodeme is an elongate sclerotic piece, against the caudal extension of which the coxa articulates. Whether it belongs wholly to the epimeron, or partly also to the katepisternum, could not be determined. The elongate sclerotic pieces on the prothorax and metathorax, against which the coxae articulate, are called simply the pleural sclerites (*pl*).

The metathorax is composed of two sections. A bridge (*pcx*), corresponding to the mesothoracic postcoxal bridge, connects the posterior section of this segment to the pleural sclerite.

Except for the apparent obliteration of the first abdominal segment, all the remaining abdominal segments are similar to those of the dorsal surface.

### ANTENNA

The antennae (fig. 7, *D*) may vary considerably in size, but the relative lengths of the segments are fairly constant. The average length measurements, in microns, for each segment of 15 antennae were: Basal 22.4, second 16.9, third 37.0, fourth 39.2, fifth 38.0, sixth 36.3, seventh 36.8, eighth 35.8, ninth 38.4, tenth 31.8.

Every antennal segment bears 1 or more setae, which range from small on the basal segments to relatively large on the apical ones. There is much variation in the numbers of these present on the different segments, a tabulation of the numbers on 16 antennae giving the following range: Basal 1, second 1, third 1 to 2, fourth 1 to 9, fifth 1 to 7, sixth 6 to 10, seventh 4 to 13, eighth 7 to 12, ninth 2 to 13, tenth 5 to 9. Each segment from the third to the tenth bears from 4 to 6 irregular transverse rows of minute spines.

### SETAE

There are 7 mesal head setae, 5 on the meson of a small raised area and a pair caudolaterad of the others. There were never any more than this, and on 5 individuals the posterior seta on the meson was absent. The mesal one of the paired caudolateral setae was absent on one side in each of 2 individuals.

The mesal setae of the abdomen and the submarginal setae are present essentially in the same numbers, positions, and occurrences as in the two preceding stages, except for the addition of a submarginal one on the ninth abdominal segment, which also has a marginal seta.

All the setae of this surface are small, their calyces about $2\mu$ in diameter, except the lateral one of the pair on the head, which is somewhat larger.

### EYE

The eye is almost circular, approximately $20\mu$ in diameter, and is situated well toward the meson.

### LEGS

The prothoracic legs are the smallest, the mesothoracic ones slightly larger, and the metathoracic ones a little larger still. The tibia and tarsus are distinctly separate, in contrast to their fusion in the first stage. The tarsus is probably one-segmented, though it is distinctly constricted near its base, giving that part the appearance of being a separate sclerite. Slight variations in the dimensions of the segments, not worthy of note, were observed, but the following measurements, in microns, of the lengths of the parts of a prothoracic leg may be taken as approximately characteristic for all the legs: Coxa 47, trochanter 47, femur 90, tibia 90, tarsus 60, claw 18.

Each segment of the legs (fig. 7, *C*) bears 2 or more setae. On 7 specimens representing all the host palms considered, the parts of

the legs were found to bear setae as follows: Coxa 5, trochanter 2, femur 3 to 7, tibia 10 to 17, tarsus 16 to 20, claw 2.

The setae on the coxa are in characteristic locations, as represented in the figure. The 2 caudal setae on the upper surface, near the articulation of the coxa to the trochanter, are generally somewhat larger than the others. The trochanter possesses a very minute seta near its proximal end, on the margin, facing the coxa; on the opposite margin, near its distal end, is a much larger one. These setae are thus situated on all the legs. The setae on the femur are somewhat variable in position. There is, however, always 1 on the margin facing the coxa, and there are 2 or more near the distal end. Those on the tibia and tarsus occur irregularly around these segments, on the distal two thirds. The tarsus always bears the larger number, usually 3 or 4 more. The 2 long setae on the distal end of the tarsus and the 2 moderate-sized setae at the base of the claw are never absent.

As in the first-stage nymphal leg, 4 distinct but small porelike spots occur, 2 each on opposite sides, near the proximal end of the trochanter.

The tibia and the tarsus possess apparently the same sort of minute spines as are present on the antenna.

### STYLUS

The stylus (fig. 7, *G*), if it is considered as constituting the ninth abdominal segment, excluding its enlarged base, consists of two fundamental parts, the genital sheath (*gsh*), which composes the outer parts of the long caudal projection and is deeply depressed along the ventromeson, and the penis (*pen*), a slender rapierlike organ extending the length of the sheath and surrounded by it. The sheath has a number of swellings (*sw*) near its distal end along each side. Usually there are 4 on a side, and occasionally 3 or 5. Each contains a dark spot or nucleus. These swellings are probably tactile in function. The penis arises within the swollen basal part of the ninth abdominal segment, and is strongly sclerotic proximally, but gradually becomes less so till it is almost membranous distally. Within the sheath the penis apparently is a round tube, which slowly decreases in diameter towards the tip, where it becomes suddenly pointed (fig. 7, *E*, *F*), with the external opening, the meatus (*mea*) (represented by the dotted lines), on the under or dorsal surface. Distally the penis is but loosely clasped by the sheath.

## SCALES [5]

The scale of the first instar is subcircular, approximately 0.4 mm in diameter at the time of the first molt, thus just covering the exuvia caudocephalad. At this time a comparatively thick mass of wax is present, which tapers toward the margins, but the darker exuvia is plainly discernible beneath.

The color of the first exuvia of both sexes beneath the secretions is rather uniform for any one specimen, but for different specimens, even those close together on a single leaf, it grades from light brown

[5] Descriptions based on dried material.

to almost black. There appear to be more of the darker forms on the date palm, but much gradation of color is noted among the specimens from all four palms.

When fully developed, the scale of the second-stage female is subcircular, approximately 0.7 mm in diameter, with the first exuvia projecting beyond the anterior margin at varying angles but in a general cephalic direction. At the time of the second molt the scale extends about 0.5 mm caudad of the first exuvia.

The adult female scale, when fully developed, is oval, more sharply so anteriorward, approximately 1.3 mm long by 0.7 mm wide. The secretion extends around the anterior margin as a very narrow band. Posteriorward this band increases in width, extending 0.3 to 0.35 mm beyond the caudal margin of the second exuvia. The first exuvia continues to project beyond the anterior margin of the scale, in a generally cephalic direction. The second exuvia appears orange colored beneath the scale, usually with a darker central area of varying proportions. This darker area appears black beneath the scale but greenish black when the scale is removed. It may almost cover the exuvia, or it may be reduced to a small central arrow-shaped area, the long point directed caudad. Sometimes it is lacking entirely, the exuvia appearing uniformly orange colored. Another specimen. almost touching one lacking the dark area on the exuvia, may, on the other hand, have the exuvia practically covered with the dark area. The date-palm material in the writer's collection has a larger number of specimens with comparatively extensive dark areas on the exuviae; yet here, as well as in the material from the other palms, all gradations in extent of the dark area on the exuviae occur.

The exuviae of the second, third, and fourth instars of the male are too delicate to show through the heavy scale covering secreted by the second instar. When fully developed, the scale covering is elongate-oval, the anterior end being somewhat sharp in contour, approximately 1.0 mm long by 0.4 mm wide. The first exuvia projects beyond the anterior margin in a general cephalic direction. It ranges from light brown to nearly black in color, each individual exuvia, however, being practically all the same shade. Here, too, there are more specimens with the darker exuvia in the date-palm material.

In color the scale coverings of all the stages from all four palms are white or nearly so. The older male specimens appear somewhat more yellow than the females, probably because of the denser secretions. In size there is some slight variation among the specimens of each stage, but none distinctive for those from any particular palm.

In molting, the ventral skin of the first instar splits crosswise just caudad of the antennae and along the lateral margin of the body and, with all its remaining parts, rolls back onto the pygidium. This same phenomenon takes place in the second-stage female, except that usually the split is somewhat more mesal all around, leaving proportionately less tissue to roll back. Apparently the entire exuviae of the second, third, and fourth male instars are pushed back to the posterior region and left in a crumpled mass.

## THE HEAD SKELETON AND ASSOCIATED PARTS

Detailed accounts of the head skeleton and associated parts are given by Berlese (*1*, *v. 5*), List (*7*), and Mark (*9*), these being in all probability the most exhaustive treatises on the subject extant. List and Mark, particularly the latter, make specific mention of the points where their observations led them to differ with the literature of their times. Both give good bibliographies.

The structures included in the sclerotic head framework (figs. 8, 9, 13, and 14) of the Coccidae have been called collectively the "Horngraten" by Mark. This seems rather a fanciful term. List's term "Schlundgerüst" is not adequate, for this framework is composed also of certain pieces intimately associated with the mandibles and maxillae. Berlese has called these structures the "rostro", which seems entirely unsuitable, since "rostrum" is a common word for the labium of the Hemiptera. A particular word to designate the parts would be desirable. For lack of one, the general term "head skeleton" will be used here. The associated parts are chiefly the coiled mouth parts, with covering membranes, and the rostrum. They are so closely linked with the head skeleton that all can be most conveniently discussed in one general section. It may be mentioned here that an entire new set of all these parts is produced for each instar. Mark (*9*) describes in detail the shape of the head skeleton of *Aspidiotus nerii* Bouché and its constituent parts, and this description he indicates as essentially covering the cases of allied genera. Berlese's descriptions of the head skeleton in a number of species of the diaspidines are in general accord with that of Mark. The head skeleton of *Parlatoria blanchardi* is, as might be expected, for the most part essentially in agreement with these two accounts.

To designate some of the boundaries of the head skeleton, the following unpublished terms of the late A. D. MacGillivray are used: "Inferarca", "superarca", "infercosta", "supercosta", and "interarca." The first four are modifications of Mark's terms "arcus inferior", "arcus superior", "costa inferior", and "costa superior", respectively. "Interarca" takes the place of the "columella" of Mark, because the structure it represents is in the form more of an arc than of a column, and "inter" indicates its position.

### ADULT FEMALE, OR TYPE

In the following paragraphs the head skeleton of the adult female is used as a type (figs. 8 and 9). The ventral surface (*vs*) is broadest cephalad, appearing dome-shaped. It narrows slightly laterally in a caudal direction to more than half its length, then bends rather sharply caudad to a distinct point. A broadly curving ridge (fig. 9, *C*, *vsr*) of this surface is directed toward this point. This surface is covered by the membranous tissue characteristic of the entire body. As far as can be observed, no part of the head skeleton projects above the general surface, although the latter appears roundly raised, particularly caudad, where it dips inward. The ventral surface is the only one in contact with the external body wall.

Cephalad the ventral surface of the head skeleton is bounded by the comparatively narrow inferarca (figs. 8 and 9, *B*, *ina*), which

joins laterally the ventromesal margins of the pair of vaulted, curving bars, the interarcae (figs. 8 and 9, *B*, *ita*), which extend at right angles from the former into the lumen of the body. Along

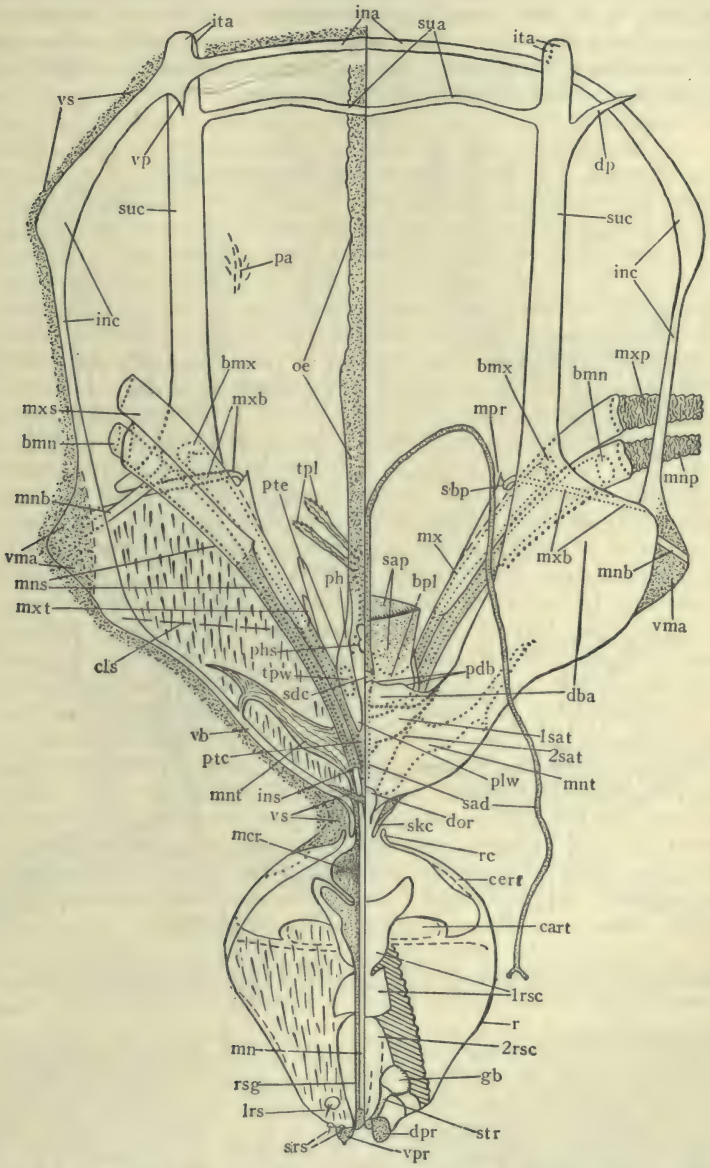


FIGURE 8.—Adult female, head skeleton and rostrum (ventral surface at left of observer). × 845.

the ventrolateral margins of the interarcae, and continuing the dome-shaped cephalic border of the ventral surface, the infercostae (figs. 8 and 9, *A*, *B*, *inc*) begin as comparatively broad bands. About midway of their lengths they narrow noticeably, and bend

from a caudolateral direction to a caudomesal one, to about the median point of the head skeleton. Here the laterial margins connect with some membranous tissue, the ventral membranous area (figs. 8 and 9, *A*, *vma*), which merges into the moderately sclerotic band (fig. 9, *B*, *lb*) covering the caudal half of the entire lateral surface of the skeleton. The infercostae are considered as continuing to a suture (fig. 8, *cls*). From here a narrow band (*vb*) extends in a curving caudal direction to the meson.

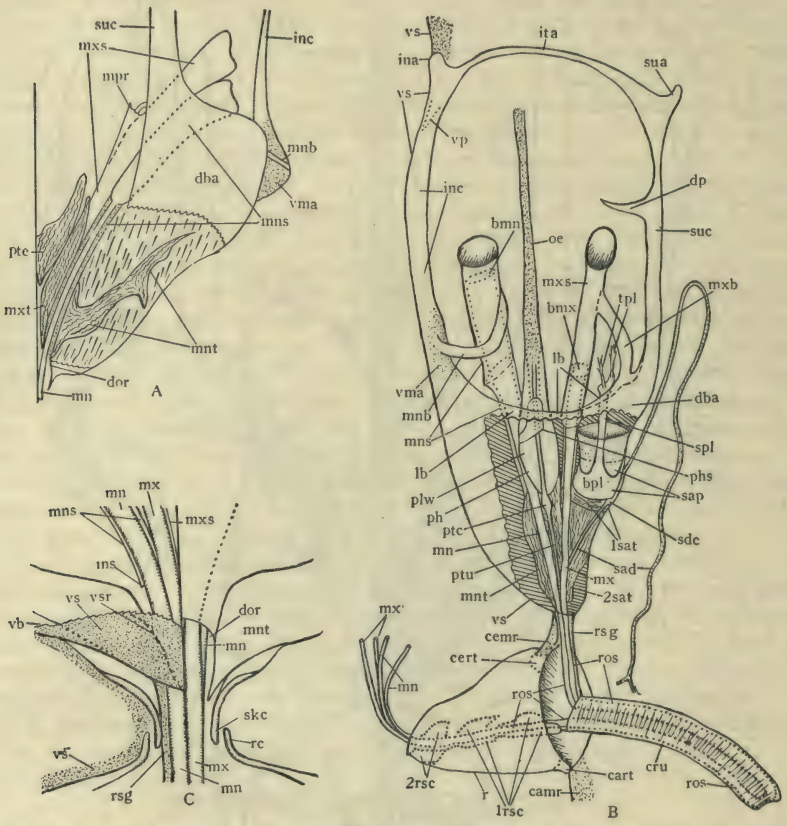


FIGURE 9.—Adult female: *A*, Intermediate dorsal aspect of head skeleton, × 700; *B*, lateral aspect of head skeleton and rostrum, × 560; *C*, articulation of head skeleton and rostrum (ventral surface at left of observer), × 2,800.

The suture beginning at the caudal end of the infercostae and extending across the ventral surface is prominent, and may in this region separate the labrum from the clypeus. Berlese considers the ventral surface of the head skeleton to be a union of these sclerites. If this is so, this suture is in all probability the clypeolabral suture. It is frequently of irregular curvature. In the figure the long dash lines simply indicate its position, since the surface tissue is represented as removed.

Projecting caudad from the ventral ends of the interarca, and flush with the membranous tissue of the body, is a pair of spinelike processes, the ventral processes (figs. 8 and 9, *B*, *vp*). These pro-

jections point toward very faintly sclerotic areas near the central part of the ventral surface of the skeleton, the process areas (fig. 8, *pa*).

The interarcae extend dorsad from their union with the inferarcae and infercostae, and join the superarca (figs. 8 and 9, *B*, *sua*) and the supercostae (figs. 8 and 9, *B*, *suc*) at a common point. The superarca limits the cephalic margin of the dorsal surface of the skeleton. It is a slender bar, at first slightly arched, then dipping caudad to the meson. The supercostae are broader bars and limit the lateral margins of the cephalic half of the dorsal surface. At their caudal ends they expand and merge into the broad dorsal bands (figs. 8 and 9, *A*, *B*, *dba*), which limit the remaining part of the cephalolateral margin of the dorsal surface. Along the cephalolateral margin of each supercosta occurs a prominent projection, the dorsal process (figs. 8 and 9, *B*, *dp*).

The dorsal bands are broadest cephalad, they narrow perceptibly caudad, and are indistinguishably fused on the meson. They might, in fact, be considered as a single band across the caudal part of the dorsal surface. Their cephalomesal margins usually have one or more slight prominences (fig. 8, *pdb*). The caudomesal margins are considerably invaginated to form the caudal boundary of the opening for the mouth parts (figs. 8 and 9, *A*, *dor*).

The ventral, lateral, and dorsal bands form a single piece, and apparently serve as a unit in holding the caudal half of the skeleton rigid. The bars apparently serve a similar function in holding the cephalic half of the skeleton rigid. Where the various bars and bands join one another the fusion is practically indistinguishable, the separation of the parts being based on form and position.

Attached to the cephalolateral margin of each ventral membranous area is a slender bar, the mandibular brace (figs. 8 and 9, *A*, *mnb*), which curves cephalomesad around a prominent strongly sclerotic tube, the mandibular sheath (figs. 8 and 9, *A*, *B*, *C*, *mns*), and flares slightly where it is rigidly joined to the dorsal surface of the sheath. The connections take place a short distance from the cephalic open end of the sheath. The sheath curves gently caudomesad and ends probably a little cephalad of the caudal point of the ventral surface. Because of the crowding of structures in this region, the exact location could not be determined. The cephalic sclerotic portion of the sheath is nearly cylindrical, and is slightly smaller caudad. The heavy sclerotization ends rather abruptly, at about half way caudad, the remaining portion being very delicate and easily overlooked.

Attached to the cephalolateral margin of each dorsal band is a slender bar, the maxillary brace (figs. 8 and 9, *B*, *mxb*). This bar curves cephalomesad and connects with the cephalic end of a long, triangular projection, the maxillary process (fig. 8, *mpr*), which is fused to a prominent strongly sclerotic tube, the maxillary sheath (figs. 8 and 9, *A*, *B*, *mxs*). This structure curves gently caudomesad, and ends dorsad of, and in the same general vicinity as, the mandibular sheath. The cephalic opening of the maxillary sheath is oval, rather than round like that of the mandibular sheath, and the sclerotization extends farther caudad; its end is less noticeable. The maxillary sheath, however, is somewhat smaller in diameter in this

region. The caudal half is delicate, its limits being difficult to distinguish because of the proximity of surrounding structures.

In all the literature that the writer has seen, the sheaths are apparently mistaken for the bases of the mandibles and maxillae, but the latter can be seen either partly or entirely within the sheaths; and also, during ecdysis, the new mandibles and maxillae can be easily observed entering the new sheaths while the old head skeleton and all its associated parts are in process of being discarded.

The mouth bristles, or stylets, come together to form a sucking tube. This tube has frequently been called the "proboscis" by American writers, but as this term has been used to include a lesser number of parts in the case of other insects, or other parts than those forming the tube among the Coccidae, it is not a distinctive expression. "Bristle" has also been commonly used, but this is even less satisfactory, since it calls to mind a short, stiff, blunt structure, such as a seta or spine, just the opposite of its meaning here. List employs "Borstenbundel", which, although implying more than merely "bristle", is open to the same objections. Mark's term "Schnabel" is not precise, for it might be thought to refer to the rostrum. Furthermore, "snout" or "beak" is used commonly to designate the prolongation of a beetle's head, including structures entirely different from the ones referred to among the scale insects. "Stylet" or "stylets" is not satisfactory, for this term has been definitely applied to the genital armature of the male coccid, as well as to other structures of the insect body. MacGillivray uses "rostralis." Although one cannot be sure through analysis exactly what the word means, it can be seen that a structure associated with the rostrum is implied. Since the word is distinctive in that it designates nothing else, just as "rostrum" is coming to mean, among sucking insects, solely the labium, formed to hold the tube, the writer has adopted it here.

Mark (*9*) quotes Mecznikov (*10*) as stating that the mandibles and maxillae appear early in the embryo, only to fuse later with other parts of the head, and that the bristles forming the sucking tube are entirely new structures, secreted from flasklike cells on each side of the head. Mark does not refute this statement; neither does List. The writer believes that much more evidence will have to be submitted to disprove the homology of these parts with the mandibles and maxillae.

A mandible (*mn*) and a maxilla (*mx*) develop in a single coil (fig. 10, *A*) on each side of the head, each one making about nine loops. Each is entirely separate from the other, and in specimens cleared in potash the loops frequently show considerable irregularity in size and position.

The mandibles and maxillae can readily be distinguished from one another by differences in their bases. The mandibular base is somewhat greater in diameter than the maxillary base, but has thinner walls. The walls, furthermore, are smooth, and the end is even in contour, whereas the maxillary base has ridges in its walls and the end is greatly depressed on one side and has a prominent spinelike projection in the depression. Except for the bases, no differences in size or form were detected between the mandibles and maxillae. Their bases are much swollen as compared with the remaining parts, but the mandibles and maxillae rapidly taper down from their bases

to slender threads, even in thickness to their tips, which are reduced to extremely fine points, with no teeth or other irregularities discernible. The basal ends of the mandibles and maxillae are observed to be hollow, and this condition prevails in any cross section of the mandibles and maxillae, except that their tips appear to be closed.

In developing, the tips are formed first, and are in the same position up to the time of molting (fig. 10, *A*), that is, just outside the cephalic ends of the sheaths. The remaining parts are laid down successively toward the bases. In mounted material the developing mandibles and maxillae are twisted, a condition (fig. 10, *B*) brought about, perhaps, by the comparatively flat condition in which they seem to be at first. The ribbonlike parts are composed of three

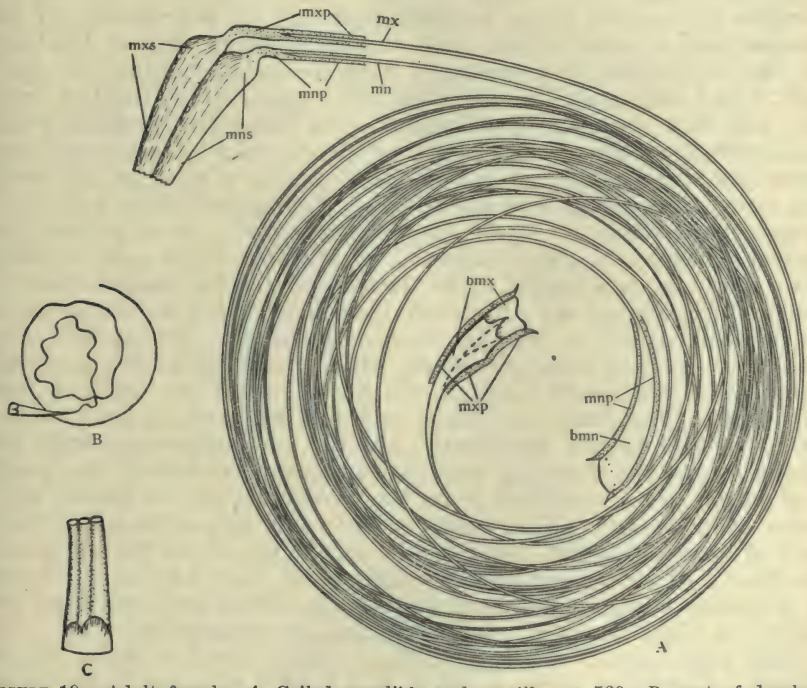


FIGURE 10.—Adult female: *A*, Coiled mandible and maxilla, × 560; *B*, part of developing maxilla, × 200; *C*, base of developing maxilla, × 800.

hollow tubules (fig. 10, *C*), which gradually become a single hollow tube toward the bases, the maxillae taking the longest time to do so.

Fused nearly at right angles to the cephalic ends of the sheaths, and surrounding closely in the coils each mandible and maxilla, are very delicate membranes, the mandibular and the maxillary pockets (fig. 10, *A*, *mnp*, *mxp*), within which the mandibles and maxillae develop. These pockets are most distinct around the tips of the mandibles and maxillae, and fade out toward the bases, where they appear to end blindly. No secreting cells at the basal ends were discerned, even in slightly cleared specimens. The pockets are considered to be invaginated continuations of the sheaths, the differences between the two being merely that of position and degree of sclerotization. A combination of sheath and pocket appears to be

produced in order to give the tremendously long mandible or maxilla sufficient room in which to develop. The sheath seems to serve the secondary function of supporting the base of the mouth part after it has slipped into the sheath. In the figure only parts of the pockets, those at each end, are shown in order to avoid too many confusing lines within the coils proper.

The mechanics involved in the forcing of the mandibles and maxillae out of the pockets and into the sheaths is not known, though a study of the musculature would probably clarify the matter. Perhaps the coils are under considerable tention. This movement begins simultaneously as the new sheaths are molted from the old ones, the tips of the mandibles and maxillae penetrating the new sheaths as fast as the sheaths are free of the old ones. During the process the pocket tissue becomes piled up at the mouths of the sheaths, and as most of it is much smaller in diameter than the bases of the mandibles and maxillae, they probably rupture it, as a rule, when they enter the sheaths. This probability, together with the fact that the pockets are forced into numerous puckers, which undoubtedly strain the tissues severely, explains why most specimens show but distorted fragments of the pockets, or none at all, about the cephalic openings into the sheaths. Occasionally the pockets of a specimen stand the strain exceptionally well; such pockets are shown in figure 8. The entrance of the mandibles and maxillae into the sheaths appears to be facilitated by the construction of neighboring parts. As previously mentioned, the mandibular brace is fastened rigidly to the corresponding sheath. But at the other end it is attached to a membrane, which probably allows a certain freedom of movement through which the sheath can be bent back and forth. The maxillary brace, on the other hand, is not attached at either end to any membrane, but the end connecting with the projection of the sheath is bent caudad and narrowed at this point, and seems to be separated from the projection of the sheath by a suture (fig. 8, *sbp*). This construction would appear to allow for a sort of pumping action, the brace being the handle of the pump. A flexibility of movement in the sheath could therefore be produced, a desirable feature inasmuch as the mandibles and maxillae are nearly at right angles to the sheaths before penetration.

The cone-shaped structure caudad of the head skeleton is the labium, or rostrum (figs. 8 and 9, *B*, *r*), as it is particularly designated among the Hemiptera. It is one-segmented, very fleshy, and deeply invaginated lengthwise on the meson of the ventral surface (fig. 11) in order to receive and hold the rostralis (fig. 9, *B*, *ros*). The rostrum is broadly rounded along the cephalic margin of the ventral surface. This margin, which is strongly sclerotic, is broken near the meson, the ends curving cephalad to form condyles (figs. 8 and 9, *C*, *rc*). These articulate against similar condyles (figs. 8 and 9, *C*, *skc*) issuing from the ventral surface membrane of the body, and in opposing positions along the mesal margin of the surface membrane (fig. 9, *B*, *cemr*, *camr*). The cephalic membrane, which is usually raised above the other body membrane, is attached along the lateral margins of the condyles, and articulates against the rostrum at two moderate thickenings (figs. 8 and 9, *B*, *cert*) of its margin. The caudal membrane articulates against the rostrum at two prominent broad thickenings (figs. 8 and 9, *B*, *cart*). Because

it is attached to the body solely by membrane, the rostrum has considerable freedom of movement in any direction.

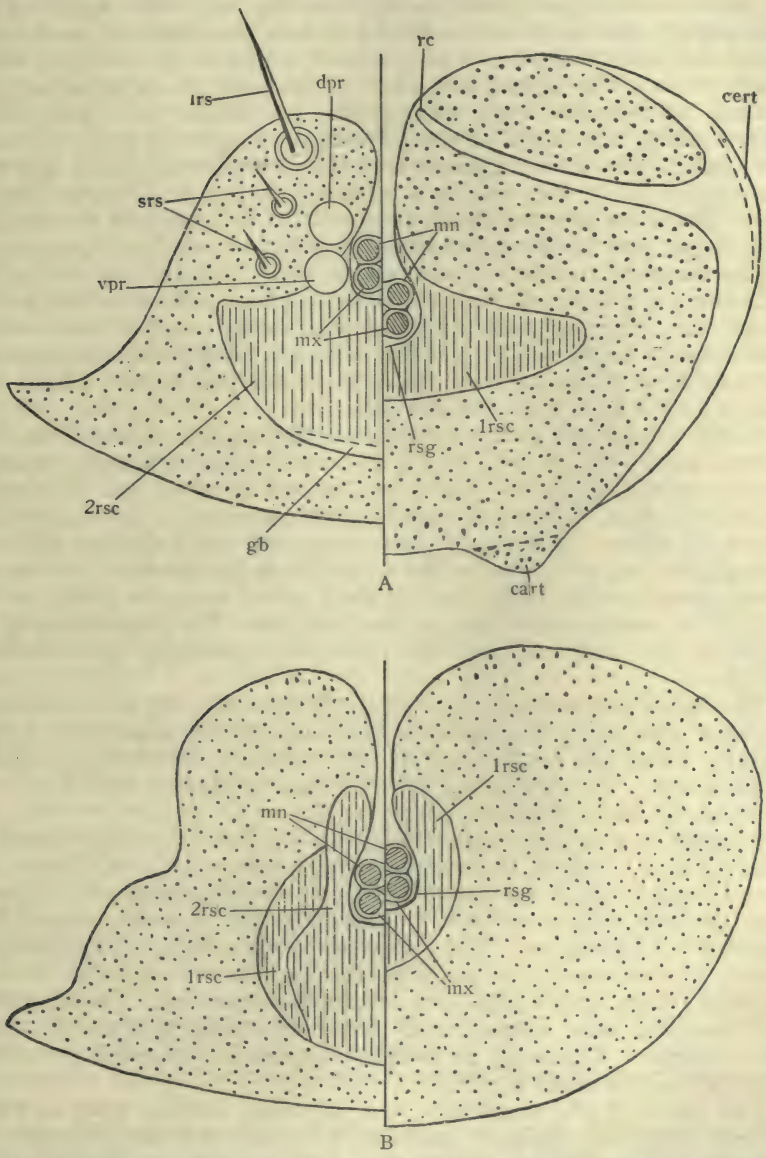


FIGURE 11.—Second-stage nymph: *A*, Apical and basal aspects of rostrum; *B*, intermediate aspects, between apical and basal. (Apical aspect at left of observer.) × 2,250.

The floor of the rostral invagination is continuous with a membrane issuing from the head skeleton. This membrane probably merges in part with the dorsal walls of the sheaths. Immediately caudad of the rostral condyles it is deeply invaginated (fig. 8, *mcr*), to form the crumena (fig. 9, *B*, *cru*) of Mark. Caudad of the cru-

mena this membrane covers the mesal floor of two sclerites, the first and second rostral sclerites (figs. 8 and 9, *B*, *1rsc*, *2rsc*). The first of these is much constricted near its center, and there appear to be two present, but since on the dorsal surface the constriction does not reach the meson, Berlese was probably right in considering this a single piece. The second sclerite is arched, simple in outline on the ventral surface, but more complicated on the dorsal. Two ridges extend along the length of the sclerite, curving toward the meson at the caudal end. Pointing in nearly the same direction is a spinelike thickening (fig.8, *str*) which is attached to a globular base (fig. 8, *gb*). The sclerite extends caudolaterad of this base to the margin. The ridges and thickenings evidently help to strengthen this part of the rostrum and to hold the rostralis in place. On the ventral surface a similar purpose is effected by the tall arched portion of the sclerite which lies over the rostralis, and the strong caudal point which undoubtedly holds and guides the rostralis. Furthermore, the membranous floor of the sclerites lies in a groove (fig. 8, *rsg*) of the sclerites, along which the rostralis slides.

At the caudal end of the rostrum are three pairs of setae, the large rostral setae (fig. 8, *lrs*), which are easily observed, and the small rostral setae (fig. 8, *srs*), which are more difficult to see. Dorsad of the setae are two delicate roundish prominences (fig. 8, *vpr*, *dpr*), one above the other. The upper, or ventral, one has a distinct but delicate projection, which looks like a small seta but probably is not one. These prominences are joined on their mesal margins to the caudal end of the membranous floor of the sclerites. Their positions at the apex of the rostrum indicate that they probably have sensory functions.

The tip of the rostralis, in issuing to the exterior, passes over the crumena and along the membranous floor of the rostrum to project slightly from the caudal end of the rostrum, undoubtedly against plant tissue. The remaining part of the rostralis is forced into the crumena by the unwinding of the coils.

Because in a large number of newly molted individuals, perhaps as many as a hundred, the rostralis, when not in the coils, was always found looped within the body, usually to its full extent, it is believed that the rostralis is always forced into the crumena before it is inserted into the plant. The frequency with which individuals were found in this condition leads to the conclusion that the rostralis remains for an appreciable time within the crumena. The mandibles and maxillae were never found partly unwound and partly within the crumena. Evidently as soon as the exuvia is rolled out of the way the coil unwinds rapidly.

The bases of the mandibles and maxillae usually pass down no further than the cephalic portions of their sheaths, although the exact location varies. Sometimes, even in old specimens, one or more bases will partially protude from the cephalic ends, others may be sunk low in the sheaths. This apparently means that the parts can function in various positions. Mark states that the tips of the rostralis may enter the crumena. This hardly seems possible, considering their sharpness, and has never been noted by the writer. On the contrary, in all the many specimens observed the tips have passed directly into the rostrum while the coils were still unwound.

Before the rostralis enters the crumena, the latter is in the wrinkled condition, and typically in the position, shown in figure 12. It is readily observed in all well-stained specimens. After entrance of the rostralis the crumena is stretched to six or seven times the length of the body, and is looped within it in a manner which is decidedly irregular, at least in prepared specimens. After the rostralis is withdrawn from the crumena, the latter shrivels up until it is greatly reduced in length (fig. 9, *B*). In this condition it is also readily observed in well-stained specimens, though frequently it appears badly distorted.

The shape and position of the rostral sclerites suggest that, when the rostralis is forced into the palm tissue, they slide back and forth upon one another, bearing down all the while on the rostralis, first on one side and then on the other. Since the rostralis is apparently unwound and within the delicate crumena before the palm tissue is penetrated to any extent, and much the greater part of it is eventually inserted into the host plant, this view of the mechanics of the rostral parts appears reasonable.

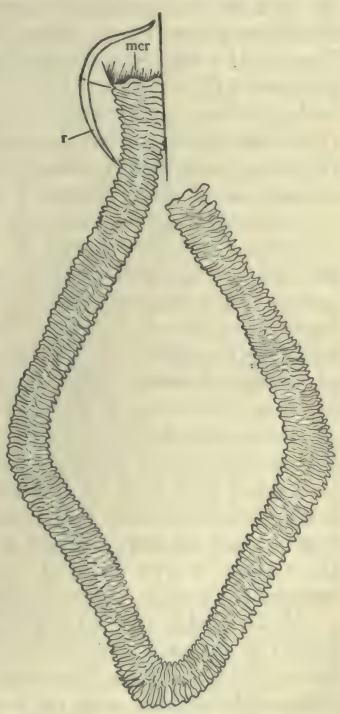


FIGURE 12.—Crumena, before entrance of rostralis, second-stage female. × 600.

On the median line of the skeleton, in a plane between the mandibles and the maxillae, is a swollen structure, the pharynx (figs. 8 and 9, *B*, *ph*). Its walls (figs. 8 and 9, *B*, *plw*) are greatly thickened laterally, but ventrodorsad they are comparatively thin. Within the walls, on each lateral side, is usually observed a rather distinct oval thickening (fig. 8, *tpw*). Piercing the thickened walls of the pharynx on the median line, a small delicate tube, the pharyngeal tube (fig. 9, *B*, *ptu*), extends to the point where the rostralis is formed. Immediately caudad of the pharynx this tube is distinctly expanded bulblike into the pharyngeal tube chamber (figs. 8 and 9, *B*, *ptc*). From its structure the pharynx appears to be a powerful pump, and undoubtedly draws the nutritive substances through the pharyngeal tube.

On the median line of the pharynx lies a sclerite, characteristically shield-shaped as viewed from the ventral surface. This is the pharyngeal sclerite (figs. 8 and 9, *B*, *phs*), which serves, according to Mark, for the attachment of muscles. From the lateral aspect (fig. 9, *B*) the pharyngeal tube extends cephalad, and appears to pass through the pharyngeal sclerite and cephalad into a large, membranous tube, the esophagus (fig. 9, *B*, *oe*). The sclerite appears to have a direct influence upon the operation of the tube. It is quite different in appearance laterally and ventrally, on account of the prolongation of its base, which, however, does not project beyond

the surface of the pharynx. Berlese (*1, v. 5, pp. 16–17, figs. 185, 186*) figures the pharyngeal sclerite as being entirely outside the pharynx in *Aspidiotus limonii* Sign. (apparently synonymous with *A. nerii* mentioned above), and presumably he believes this is the case for related forms.

Immediately dorsad of the pharynx, and close against the dorsal surface of the skeleton, is a cuplike structure, the base of which is rounded and thickened, the lower sides thickened and directed inward, and the upper sides thin and directed outward. This structure is designated the salivary pump (figs. 8 and 9, *B*, *sap*). Arising from its center and directed cephalad is a rodlike projection called the salivary plunger (fig. 9, *B*, *spl*), which expands gently, and ends in two prominences, a small ventral one and a longer dorsal one. Each prominence is capped by a small tendon (figs. 8 and 9, *B*, *tpl*). Nearly the entire lower half of the pump is filled by the base of the plunger (fig. 9, *B*, *bpl*).

A delicate tube, the salivary duct (figs. 8 and 9, *B*, *sad*), issues from the caudodorsal point of the pump, extends free of the skeleton into the body cavity some distance cephalad, and bifurcates. Each branch is at first directed cephalolaterad, then bent rather sharply in a caudal direction, and in turn bifurcates in the region of the rostrum. Berlese gives the salivary duct as penetrating the walls of the pump (ghianda), but to the present writer it appears to enter the pump just cephalad of the margin of the dorsal band, bend beneath the pump for a short distance, and expand into a bulblike chamber (fig. 9, *B*, *sdc*). In this particular it resembles the pharyngeal tube. Beyond this the salivary duct extends in a caudoventral direction toward the pharyngeal tube. Berlese states that it ends in a large chamber. Nothing like this was discernible to the writer, but a narrow tube, smaller and darker than the pharyngeal one, and deeply imbedded in tendonous tissue, appeared to be present. As far as could be determined, this salivary-duct tube did not extend so far caudad as the pharyngeal tube, and ended before the rostralis was formed, indicating that the salivary tube probably connects directly with the pharyngeal tube.

About half way along each ventral band there is joined to it a curving, strongly sclerotic structure. Laterad this structure tapers to a point against the lateral band, and mesad it expands against the caudolateral side of a mandibular sheath, tapering against it both cephalad and caudad. From its shape and position it is thought to be a tendon, and it is here designated as the mandibular tendon (figs. 8 and 9, *A*, *B*, *C*, *mnt*). Besides covering the entire lateral surface of a mandibular sheath, this tendon curves slightly and covers in this region some of both dorsal and ventral surfaces of the sheath. The parts of the tendon connecting it with the ventral and lateral bands apparently serve as braces. On the ventral surface, mesad of the maxillary sheath of each side, there is just visible a projection that is considered to be a part of the maxillary tendon (figs. 8 and 9, *A*, *mxt*). This tendon covers some of the mesal surface and much of the dorsal surface of the maxillary sheath; it tapers caudomesad, coming to an end on the dorsal surface.

With the position of these tendons in mind, the manner in which they operate on the parts concerned may be considered. The mandibles are apparently clasped, chiefly laterally, and partly ventrally

and dorsally, by the mandibular tendons, and forced mesad. On the other hand, the maxillae appear to be clasped or imbedded in the maxillary tendons mainly dorsally but partly mesally, and would therefore be forced ventrally and laterally against the mandibles. The mandibular tendons are larger, and also much more extensive laterally, than the maxillary tendons are mesally. As a result the maxillae are pressed against the mandibles directly beneath (dorsad), while the maxilla and mandible of each side are being brought together on the meson by the more powerful mandibular tendons. In this way the rostralis would be produced in the region of the caudal end of the head skeleton. The rostralis is square in cross section, with apparently a single sucking tube in the center. Unfortunately, no good cross sections of the rostralis were obtained; so the writer hesitates to state this positively, though the cross sections he did have appeared to have the parts in these positions, as would be expected from the position and shape of the tendons. List (*7*), however, states that for *Orthezia cataphracta* Shaw the maxillae are placed, one dorsally and the other ventrally, in juxtaposition, a concavity in the surface of each producing a central tube, while a mandible is placed on each side, a concavity in each pressed against the median line of the maxillae, producing two secondary tubes, resulting in three sucking tubes altogether.

On the ventral surface, mesad of a maxillary tendon, is another, considerably larger, pointed structure, the pharyngeal tendon (figs. 8 and 9, *A*, *pte*). This tendon covers the lower part of the pharynx laterally and dorsally, and tapers sharply to an end on the dorsal surface. The pharynx is cupped within this tendon, which on contraction would apparently squeeze it. Perhaps, however, this tendon serves the greater purpose of holding the pharynx steady, while the powerful walls of the pharynx do the contracting during the pumping operations. In either case the pharynx is considered to be the pump which draws the substances into the alimentary tract. The bulblike chamber of the pharyngeal tube seems to serve as a vacuum chamber.

Immediately dorsad of the pharyngeal tendon, and just beneath (caudad of) the salivary pump, lies the thickest of all the tendons of the head skeleton, the first salivary tendon (figs. 8 and 9, *B*, *1sat*). It is the only one which extends to the dorsal band. Cephalad this tendon expands slightly against the meson some distance below the cephalic margin of the dorsal band; caudad it expands more appreciably, with a small part of it tapering out against the salivary duct. Laterally this tendon curves, and tapers sharply to a point at the margin of the dorsal band. Caudad of the first salivary tendon lies the second (figs. 8 and 9, *B*, *2sat*), which tapers from the whole caudal margin of the former to the caudal invagination of the dorsal band. This second salivary tendon also covers like a sheet the whole dorsal surface of the lower part of the maxillary tendons. The mandibular tendon extends far enough around dorsad to expand against the ventrolateral surface of the second salivary tendon. The salivary plunger apparently works up and down, the pump being the framework which holds the plunger steady. The tendons of the plunger probably instigate its up-and-down movement. The strong first salivary tendon supports the pump and holds it in

place, as well as the part of the salivary tube penetrating it. The bulblike chamber of the tube probably serves as a vacuum chamber, being similar in function to that of the pharyngeal tube. The second salivary tendon guides the remainder of the caudal part of the tube, and probably also supports the dorsal surface of the mandibular and maxillary tendons, and helps to bind together in this region the free ends of the tendons.

## VARIATIONS FROM TYPE IN OTHER STAGES

The head skeleton and associated parts of the first and second instars are essentially like those of the adult female, although smaller. To indicate to better advantage most of the parts of the head skeleton and rostrum, certain parts are featured in each of figures 1, 3, 4, 5, and 6. In the first instar the ventral processes and process areas appear to be missing, whereas in the second instar of both sexes they are prominent. The superarca, inferarca, and interarca are membranous in the first instar, and somewhat less so in the second, especially the inferarca, which approaches the sclerotic condition. No sex differences were found in the head skeleton and associated parts of these two stages.

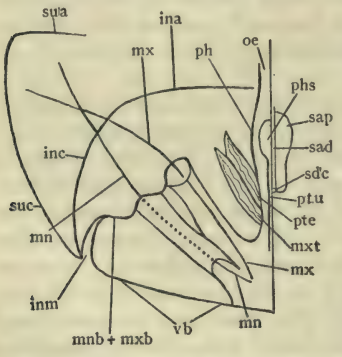


FIGURE 13.—Developing head skeleton of embryo (ventral surface at left of observer). × 2,000.

Figure 13 shows the condition of the head skeletal structures in an early embryo. It may give some indication of the formation of these parts in older stages, about which it is difficult to gain information owing to the intimate presence of the old, strongly sclerotic parts. Most of the parts can be recognized. The interarca and the lateral and dorsal bands are not distinguishable, but the ventral band appears as a single curved line, like the bars, just as it resembles these in form in the older stages. The mandibular and maxillary sheaths and the pharynx are distinctly invaginated, each opening into a common chamber. The membranes of the mandibular sheath can be seen almost to the point of invagination. A mandible and a maxilla are distinct within the sheaths as simple curving lines. At the bottom of a deep invagination (*inm*) a twisted line is observed to arise and connect both sheaths, circling around the maxillary one. Considering that one line connects both sheaths, it is thought to be a combination of the mandibular and maxillary braces. These appear to begin there as a single invagination. A theory of their later development is that the two braces split in the direction of the invagination, which becomes filled with tissue by the two braces stretching away from each other, producing the cephalic part of the lateral band. The pharnygeal tube is distinct, leading directly into the pharyngeal sclerite. The comparatively wide mouth of the invagination on each side of the tube is apparently filled later with the pharyngeal wall tissue. The maxillary and pharyngeal tendons were distinct, but the mandibular tendon was not distinguishable;

neither were the tendons associated with the salivary apparatus, though both salivary pump and duct were plainly discernible.

The head skeleton of the third-stage male is distinct, and also the outline of the rostrum, though there is no visible connection between the two. The bars and the bands are all present, though in a membranous condition, and can be readily recognized (fig. 14, *A*). The sheaths, braces, mandibular and maxillary pockets, crumena, mandibles, and maxillae could not be distinguished. The pharynx, however, apparently persists. It is membranous, except for the pharyngeal sclerite, but is distinct. The salivary duct is also apparently distinct, and seems to be divided into two tubes as far as its point of invagination. Only one tube was distinguishable in some specimens. The salivary pump is extremely vestigial, but the faint outline of its lower sides can be made out. The rostrum is recognized

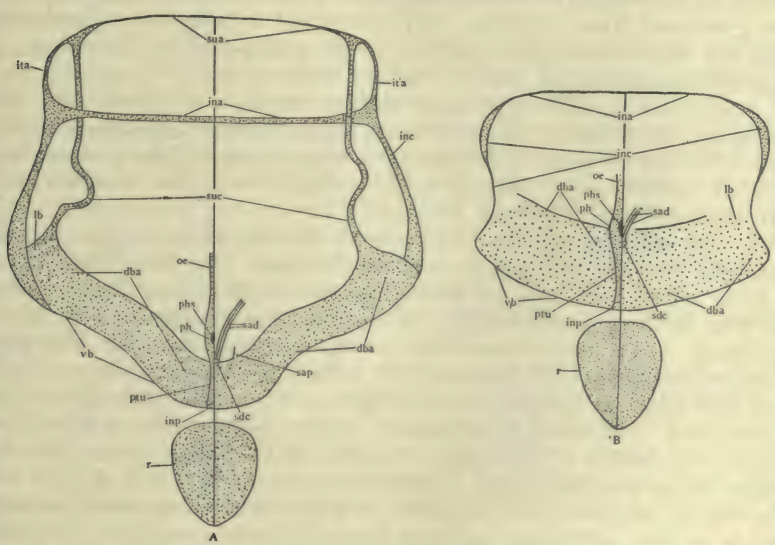


FIGURE 14.—Head skeleton and rostrum: *A*, Third-stage male; *B*, fourth-stage male. (Ventral surface at left of observer.) × 800.

by its typical shape, position, and constant presence. It is an undifferentiated membrane.

The head skeleton of the fourth instar (fig. 14, *B*) can also be distinguished, but it is not so noticeable as that of the third instar on account of its smaller size and the smaller number of parts in the framework, which is composed of more delicate membrane. All parts absent in the third-stage male are absent in this stage, and, in addition, the superarcae, the interarcae, the supercostae, and the salivary pump; also, the lateral and dorsal bands are not complete, the former being almost lacking. The remaining corresponding parts, including the rostrum, are almost, if not quite, as noticeable as they are in the third-stage male.

The pharyngeal tube is apparently present in the adult male. No other parts of the head skeleton or any associated with the head skeleton could be definitely distinguished in this instar.

Measurements, in microns, of typical head skeletons of the various instars were: First, length 66, width 46; second female, length 110, width 83; adult female, length 130, width 110; third male, length 77, width 64; fourth male, length 46, width 40.

## SUMMARY

The Parlatoria date scale (*Parlatoria blanchardi* Targioni Tozzetti), probably the most serious insect enemy of the date palm, has 3 female and 5 male instars. A detailed account is given of all the distinguishable structures of the external anatomy and the endoskeleton of the head and associated parts for all instars of both sexes. For every instar except the third and fourth male instars, four or more specimens from each of the four known host palms were examined thoroughly. The number of individuals studied completely ranged from 7 to 32. All structural details proved substantially the same regardless of host. It was possible, therefore, to group the specimens of each instar for discussion.

A variation in size, position, and occurrence of structures and groups of structures is characteristic, and is frequently noted specifically. Where subject to satisfactory measurement, the average and range of variation are recorded, the number of cases used for each determination ranging from 7 to 2,378.

Sex can apparently be determined in the first stage. In the specimens studied (28 males and 24 females) the outer surface of the tibia of all six legs of the male possessed a prominent spine. This was lacking in two thirds of the females examined and in the remaining third never occurred on more than two of the legs.

The segmentation of the body is indicated for all instars. It is based not only on sutures, where these are present, but also on the number and position of the setae, pores, plates, and lobes. The head is not clearly differentiated except in the adult male. On the venter the mesothorax and metathorax are each divided into two segments or sections, the anterior section of the mesothorax being fused with the prothorax, and the first abdominal segment is apparently missing; on the dorsum neither the mesothorax (except in the adult male) nor the metathorax is apparently divided and the first abdominal segment is normally developed. The ninth abdominal segment is much reduced on both surfaces in the first and second instars and in the adult female. In the third male instar it is moderately reduced on the dorsum and occurs as an elongated invaginated projection on the venter. In the two later male instars it is well developed as a pointed caudal projection.

The structure and distribution of pores and setae follow a rather definite pattern through the various instars. A separation of them into certain groups is possible. In general, pores vary in all respects more appreciably than do setae.

The pores are limited to two fundamental types: (1) An invaginated type, possessing one external opening and within the body a single membranous tube capped by two bars, from the center of which issues a delicate club-shaped tube, and (2) a disk type. The invaginated type can be divided into two kinds, one varying in size and opening on the surface, and the other small and opening at the

peak of a raised area. The invaginated pores with surface openings occur more frequently along the margin and submargin of the thorax and abdomen, but may be present elsewhere, in the first, the two second, and the adult female instars; the raised kind is limited to the margin and submargin of the second instars and the adult female. The disk type of pore is limited to the second instars and the adult female. In the former it is present only in the region immediately cephalad of the mesothoracic spiracles, but in the adult female in this region and also around the genital opening. The three later male instars possess no pores of either type.

From stage to stage there is a general increase in the number of pores along the margin and submargin of the thorax and abdomen, and also toward the mesal region of both abdominal surfaces in the adult female. In these regions the increase in number of pores is distinctly greater in the second-stage male than it is in the female of this stage.

In general, in the female instars the setae progressively increase in number on the ventromesal region of the thorax and abdomen, and along the submargin of the thorax. Including both sides of the body, as compared with the second-stage female, the male of this stage possesses 4 to 8 more setae on each surface of the head and near the mesodorsal region of the thorax and abdomen, as well as an extra pair on the ventral margin of the eighth abdominal segment. Elsewhere the setae are essentially alike in both sexes. In the 3 later male instars the number of setae progressively increases on the head but remains approximately the same elsewhere. These 3 instars have no setae on the ventral margin and submargin of the first 3, and usually the next 2, abdominal segments.

Because of variability in the occurrence, size, and form of the lobes and plates, and in the occurrence and position of the pores, on the pygidium, this region of the body should be used diagnostically with caution. The lobes and plates are in different degrees of permanence along the cephalic margin of the pygidium, and leave little doubt of their origin as simply modified bulgings in the surface tissue.

In the first instar a prominent pair of lobes, which are usually considered by coccidologists to be the first pair, are determined as the second, with the first pair probably absent; but in the second stage and in the adult female, the prominent pair farthest caudad are determined as the first ones.

The eye is apparently present in all instars except the third and fourth male ones and possibly the adult female. In the adult female a structure that at first resembles an eye in contour and general location may bear no relation to an eye, but this matter it still unsettled. The adult male has two pairs of well-developed eyes.

The legs persist in all instars except the adult female. In the first instar they are of the usual insect type except for a fusion of the tibia and tarsus. Those in the second-stage male are decidedly vestigial, varying in development from being almost lacking to plainly discernible, with evidences of segmentation. In the second-stage female they are in general more vestigial than they are in the male of this stage. Those in the three later male instars show in-

creasing development and sharper segmentation, being fully developed in the adult male, with tibia and tarsus plainly separated.

The wings may or may not be present in the three later male instars. In the adult male the wings and the halteres are frequently in various degrees of degeneration down to complete absence. The thoracic wing framework is always present and well developed in the adult male, but is wholly lacking in the two preceding instars. Its segmentation and the structure of the articulating parts of the wing agree in general with those found in other insects.

An undetermined structure laterad of each metathoracic leg in the first instar may be a vestige of the spiracle of the first abdominal segment.

The endoskeleton of the head is composed of a number of sclerotic bars and bands joined together into a boxlike framework without marked divisions, and of other pieces concerned in the operation of the mouth stylets, pharynx, and salivary duct. It is a rather complex assembly of more than 50 different single and paired structures. These parts are all figured and discussed. The endoskeleton is essentially the same in all instars, except the three later male ones, in which it becomes increasingly vestigial, though parts of it are plainly evident in the third and fourth instars. Only the external opening to the alimentary tract and a small section of the tube can be distinguished in the adult male.

The rostrum is one-segmented and persists in distinct form in all instars except the adult male, in which it is apparently lacking. The rostrum possesses characteristic sclerites and setae, and is essentially the same in all instars except the third and fourth male ones, in which it is wholly membranous with no differentiated tissue.

The rostralis, or mouth stylets, occurs only in the first, the two second, and the adult female instars. It develops anew for each instar in coils within delicate pouches or pockets on each side of the head skeleton. Before issuing from the body it unwinds and moves into a delicate pouch within the body cavity. It has an average length more than two but not three times that of the body in the newly hatched first instar, and six times or more that of the body in newly molted individuals of the other instars.

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TECHNICAL BULLETIN No. 420 AUGUST 1934

# POPLARS PRINCIPAL TREE WILLOWS AND WALNUTS OF THE ROCKY MOUNTAIN REGION

By

GEORGE B. SUDWORTH

Late Dendrologist, Branch of Research, Forest Service

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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George B. Sudworth (1864–1927) was at the time of his death dean of the profession of forestry in this country. He had the distinction of having been the first person in the history of American forestry to receive official appointment as dendrologist, and was the oldest member of the Forest Service in point of service. His appointment in the Department of Agriculture on August 31, 1886, during the infancy of organized Federal forestry in this country, made his 41 years of official service, through the successive stages of Division of Forestry, Bureau of Forestry, and finally Forest Service, practically coextensive with American forestry development and progress. Mr. Sudworth's contributions to the advance of forest research in those years were extensive and varied, including much field study and exploration as a dendrologist, the discovery and naming of a large number of new tree species and varieties, and the collection of many valuable type specimens, as well as studies in nursery practice, wood identification, and horticulture. He was one of the framers of the so-called American code of botanical nomenclature. For 15 years he was an active member of the Federal Horticultural Board. Of his many publications on forestry, among the most important are his reports on early forest reserves and his Check List of the Forest Trees of the United States, Their Names and Ranges, a completely revised edition of which was issued only a few weeks before his death and which represented the fruit of painstaking study and solicitous attention during the four decades of his public service.

The present bulletin is sixth in a series of works by Mr. Sudworth on the systematic dendrology of western trees, of which the predecessors are Forest Trees of the Pacific Slope (1908), Cypress and Juniper Trees of the Rocky Mountain Region (1915), Spruce and Balsam Fir Trees of the Rocky Mountain Region (1916), Pine Trees of the Rocky Mountain Region (1917), and Miscellaneous Conifers of the Rocky Mountain Region (1918).

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By GEORGE B. SUDWORTH [1]

Late *dendrologist, Branch of Research, Forest Service*

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## INTRODUCTION

In a series of four preceding monographs (*86*, *87*, *88*, *89*)[2] the author has covered the coniferous trees of the Rocky Mountain region. In the present publication he discusses certain of the hardwoods of that region.

[1] Review and some revision of this posthumous manuscript has been made by Perkins Coville. It was the intention of the author to prepare keys for the identification of the species covered in this bulletin, but up to the time of his death (May 10, 1927) such keys had not been compiled. Those published herewith have been prepared by William A. Dayton, who has also enlarged and rearranged the bibliography and added certain footnote notations. In his original draft of the manuscript the author took pains to express his hearty appreciation of the unfailing assistance given by members of the Forest Service, particularly officers of the national forests, who responded to many special requests for specimens and information on range. Indebtedness was expressed to the late Mrs. A. E. Hoyle for fully half of the botanical drawings which illustrate the text; also to Mrs. N. B. Brenizer of the Forest Service; and to J. Marion Shull and Frank Bond, formerly of the Forest Service but now, respectively, of the Bureau of Plant Industry and chairman of the U.S. Geographic Board, for their share of the illustrative work.

[2] Italic figures in parentheses refer to Literature Cited, p. 105.

As defined in this bulletin, the Rocky Mountain region includes Montana, Idaho, Wyoming, Colorado, Utah, Nevada, Arizona, New Mexico, and the western part of North Dakota, South Dakota, Nebraska, Oklahoma, and Texas. The Dakotas, western Nebraska, western Oklahoma, and western Texas are included because their topographic and climatic conditions are more or less similar to those of the Rocky Mountain States and because many of the tree species are the same. For example, the Rocky Mountain form of ponderosa pine (western yellow pine) grows abundantly in the Black Hills of South Dakota and in western Nebraska, and limber pine (*Pinus flexilis*), Arizona cypress (*Cupressus arizonica*), alligator juniper (*Juniperus pachyphloea*), and other species occur in the mountains of western Texas. A number of Rocky Mountain species grow naturally also in adjacent Canadian and Mexican territory. It was necessary, in defining the range of such trees, to include this territory.

The geographic distribution of the different species is shown by photographic reductions of large folio maps on which the range data were originally plotted. It is comparatively easy to describe the range of trees in some such words as "from Maine to Florida and westward to Minnesota, Missouri, and Texas", but when the attempt is made to express such very general information satisfactorily on a map many difficulties are encountered. The statement does not indicate whether the boundary reaches the nearer or farther State line or lies somewhere within the State. Also there may be and usually are large and small interruptions or gaps within a generally described range from north to south or from east to west. In mountainous regions it is important to know also the altitudinal range of a tree. In spite of these difficulties, these reduced maps present a much more accurate outline of the distribution than would be believed possible from their small size.

In mapping the range of trees it is often necessary, for want of detailed information, to represent the range area as solid or continuous. A map so constructed is apt to give the impression that the tree concerned grows in all places throughout an area thus indicated; in reality, all it means in the majority of cases is that the tree is found within the limits of the area. In a few instances available information has been sufficient to allow the range to be indicated more accurately by a disconnected plotting.

Although the geographic distribution of a good many of the better known trees is now thoroughly delimited, further painstaking field explorations are necessary before knowledge of the range of many of the others can be completed. The extreme points actually reached in the range of these trees are yet to be discovered, and it is only through the combined efforts of students of trees that this highly desirable information can be obtained.

The information used in compiling the maps accompanying this bulletin was derived from all available published and unpublished material, including field notes and reports of Forest Service officers who in the exploration and administration of the national forests have unusual opportunities for gathering such data.

Text descriptions are put, so far as has seemed feasible to the author, in simple language. Some technical phrases, however, have seemed unavoidable, especially in the keys. For definition of those terms the reader is referred to the glossary of botanical terms issued by the Forest Service (*24*). Effort has been made to supplement the text descriptions as fully and accurately as possible by keys and illustrations. The nomenclature is that established as official for the Forest Service, as presented in the Check List of the Forest Trees of the United States (*90*). It is admitted that this usage varies considerably from that given in many botanical publications.

## FAMILY CHARACTERISTICS OF POPLARS AND WILLOWS

*Salix* and *Populus*, the two genera constituting the whole family Salicaceae, comprise a very large group of trees and shrubs. The bark of these plants is characteristically bitter,[3] particularly that of the willows, and their juices are bitter and watery. The leaves, shed in early autumn, are borne alternately on the branches, never in pairs. In willows they are short-stalked but are long-stalked in aspens and most cottonwoods and poplars. As a rule, the staminate and pistillate flowers of poplars and willows are produced on different trees,[4] and seed is therefore borne only by female trees, the flowers of which are fertilized by wind and by insects (largely bees).

Buds of both genera are scaly. In poplars all the staminate and most of the pistillate catkins droop. They come forth on twigs of the previous year's growth and appear considerably in advance of the leaves. The aments of poplar flowers differ from those of the willows in producing no leaves at their bases. The staminate flowers bear at their base a small fringed or toothed scale. In most species the pistillate flowers have a similar scale.

The fruits of poplars and willows ripen in late spring about the time the leaves reach full size. They are single-celled thin capsules (figs. 29 and 32) which split open soon after maturity into 2 or 4 sections, liberating the minute seeds. The numerous long, exceedingly fine, silky hairs on the seeds enable the wind to carry them easily for very long distances.

With some exceptions the poplars and willows are moisture-loving plants. This accounts for their prevalence along streams and in moist bottom lands. A remarkable characteristic is their ability to grow readily from root or branch cuttings and to sprout vigorously and persistently from cut stumps of almost any age and from various points on their long, shallow roots, often at great distances from the stump.

A key to the Salicaceae is presented as follows:

Flowers in cuplike, often oblique disks; floral bracts fimbriate or incised; stamens numerous (6 to 80); stigmas 2–4, entire or 4-lobed; buds resinous, covered by several scales. Trees; leaves mostly broad, typically of an ovate type (occasionally narrower), mostly rather long-stalked; aments usually pendulous ..... *Populus*

[3] The bark and fresh aments in willows and the bark of poplars yield the exceedingly bitter glucoside known in medicine as salicin.

[4] Sometimes one tree may produce clusters of male and female flowers, or even clusters combining both male and female flowers, but this is exceptional.

Flowers not in cuplike disks, subtended by 1 or 2 small glands; floral bracts entire (or at most with small teeth); stamens mostly 2 (varying from 1–10); stigmas 2, short, entire, or 2-cleft; buds covered by a single scale. Shrubs, trees, or subalpine-alpine undershrubs; leaves mostly of a narrow (often lanceolate) type, sessile or short-stalked; aments usually erect or spreading, sometimes pendulous ..... *Salix*

## GENERIC CHARACTERISTICS OF POPLARS

This large group includes the trees popularly known as aspens, poplars [5] or "popples", and cottonwoods. Several of them are very large forest trees, with rough, deeply furrowed, grayish bark (cottonwoods), or smooth, little broken, brownish green, pale green, whitish, or ashy bark (aspens). In outline, many of the leaves are broadly triangular (deltoid) or ovate; in a very few species, however, the leaves are lanceolate and willowlike. The leaf edges are occasionally uncut (entire) but more often bear fine teeth like a small saw or large and coarse or hooked teeth. When mature, the leaves are most often hairless (glabrous) on both surfaces, but in some species the hairy or woolly covering is persistent. The leaf stalks (petioles) of the aspen group of this genus are flattened at right angles to the leaf blade, and this causes the leaves to tremble in the slightest breeze. After turning yellow in autumn the leaves fall from the trees, leaving prominent leaf scars which give the twigs a knotty appearance.

The scaly buds of many species are characterized by a covering of pungent sticky resin,[6] which appears to act as a winter protection. Male and female flowers are borne on separate trees; only the female trees produce seed. Trees of the two sexes are unevenly distributed—frequently only one seed tree to many staminate or sterile trees; sometimes male and female trees are very widely separated.

The wood of the poplars is light, soft, and straight grained. The grain is sometimes fine, but is more often coarse as a result of the rapid diameter growth characteristic of these trees. The wood ranges in color from whitish to light or yellowish brown. The wood of most species is brittle, susceptible to heat and moisture changes, not durable, and formerly had no economic value; but that of a number of species is now rapidly coming into wide use and great commercial value, both for pulpwood and as lumber to take the place of other lightweight woods, the supply of which is decreasing. One of the last-mentioned is yellow poplar (tuliptree), which the wood of some of the poplars resembles in grain and in the ease with which it can be worked.

The poplars are important to the forester. They produce a forest cover and useful timber in 25 to 50 years and, like the willows, can easily and conveniently be grown from root and branch cuttings and from cut stumps, even from stakes set in damp soil. Thus artificial propagation is very simple. Maturity is reached in not more than 100 to 150 years, usually well within a century. After

[5] *Liriodendron tulipifera* L., native of the eastern part of the United States, and known as yellow poplar, is a member of the magnolia family and is not closely related to the true poplars. This species is also known as "tuliptree."

[6] Cottonwood buds are one of the chief sources from which bees derive propolis, the so-called "bee glue" with which honeybees cement cracks in their hives and fasten the combs in hives or in the hollows of trees. When hard it is very strong.

maturity the poplars ordinarily begin to show signs of arrested growth, but on account of their great vitality and recuperative power some species may continue to grow for a much longer time.

Poplars now recognized in the United States and adjacent areas in Mexico and Canada include 17 different native and naturalized species, 13 varieties, and 4 hybrids. Eleven botanical species (embracing 11 varieties) and 1 hybrid grow within the Rocky Mountain region.

The poplars are of very ancient origin. Remains show that they existed among the earliest tree forms of the Lower Cretaceous period in Greenland, and that many different species inhabited the central portion of this continent in the same epoch. They existed also in the Tertiary and Miocene periods in this country and Europe. (*14; 49; 50; 51; 52; 73; 76*, v. *9; 105.*)

## KEY TO ROCKY MOUNTAIN POPLARS[7]

Leaves lanceolate to ovate-lanceolate; petioles short (one third as long as the blades or shorter). Leaves crenulate, with blunt teeth, 5–15 cm long, 2–4 cm wide, rounded or narrowed at the base, much paler beneath; stamens 12–20; stigmas dilated; capsules ovate, rugulose; Transition and Upper Sonoran Zones ..... *Populus angustifolia*

Leaves not lanceolate (rarely ovate-lanceolate), of a broader type; petioles more than one third as long as the blades (mostly about as long as the blades or even longer).

Petioles terete, though sometimes channeled above.

Leaves rhombic-lanceolate to ovate, green on both sides, acuminate, crenulate.

Twigs and winter buds more or less resinous but not woolly pubescent. Leaves 6–10 cm long, 3–5 cm broad, abruptly long-acuminate, crenulate to rather coarsely crenate, the lower surface often somewhat paler and duller than the upper; petioles one half to three fourths as long as the blades; Upper Sonoran Zone, Saskatchewan to Texas and Arizona ..... *P. acuminata*

Twigs and winter buds woolly-pubescent. Leaves larger and longer-petioled than in typical *acuminata;* stream banks of southeastern New Mexico ..... *P. acuminata rehderi*

Leaves not at all rhombic.

Leaves usually yellow-green, not conspicuously reticulated, glabrous, oblong-ovate, finely crenate-serrate, rounded or cuneate at the base, 9–10 cm long. Petioles nearly terete; twigs light orange-brown; Colorado hybrid of *P. sargentii* x *P. acuminata.* x *P. andrewsii*

Leaves dark green above, conspicuously reticulated, much paler, and often more or less puberulent beneath.

Leaves ovate-lanceolate to cordate-ovate, about one half to three fifths as wide as long, the margins somewhat thickened and revolute; petioles usually glabrous; stamens 20–30, short, with pink anthers; stigmas 2; capsules ovoid-oblong, two-valved. Leaves minutely ciliate but otherwise glabrous except sometimes on midrib beneath, silvery whitish or pale brownish beneath, 7–12 cm long, acute or short-acuminate, rounded or occasionally cordate or truncate, rarely broadly cuneate at the base; buds highly fragrant-resinous. *P. balsamifera*[8]

Leaves broadly ovate to ovate, about two thirds as broad as long or broader.

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[7] Key prepared by W. A. Dayton, based largely on the work of Britton and Shafer (*19*), Standley (*83*), Sargent (*79*), Tidestrom (*93*), and Rydberg (*71*). Mr. Sudworth's nomenclature has, however, of course been followed. The key was also orally discussed with Mr. Tidestrom, who has a monograph of *Populus* in preparation and has contributed many excellent suggestions.

[8] This has been confused by some American authors with *P. tacamahacca* Mill.

Leaves typically cordate (rarely truncate) at the base; petioles pubescent. Leaves of a broadly ovate-deltoid type, acuminate, coarsely crenate-serrate, ciliate, usually 12–16 cm long and about 10 cm broad, slightly pubescent above, whitish and sparingly pubescent beneath, but densely so on the veins; twigs brown. Common in cultivation; the balm-of-Gilead poplar. Sargent states that only the pistillate tree is known.

*P. balsamifera candicans* (=*P. candicans*)

Leaves not typically cordate; stamens 40–60, elongated, with purple anthers; stigmas 3; fruit usually subglobose, three-valved. Leaves usually rounded at base, acute or short-acuminate ..... *P. trichocarpa*[9]

Petioles laterally compressed, mostly elongated. Aspens and allied "cottonwoods."

Leaves suborbicular, 2–6 cm long (those of rootshoots ovate), finely serrate; stigmas 2, filiform. Bark thin, smooth, pale, grayish or greenish; winter buds glabrous but somewhat resinous; the common western aspen, a Canadian Zone tree.

*P. tremuloides aurea* (=*P. aurea*)

Leaves not suborbicular; stigmas mostly 3 or 4, usually dilated.

Leaves oblong-ovate, 9–10 cm long, finely crenate-serrate, rounded or cuneate at base. Petioles nearly terete, only slightly flattened laterally; Colorado hybrid of *P. sargentii* x *P. acuminata*.

x *P. andrewsii*

Leaves of a distinctly deltoid or ovate type, acuminate, thick or thickish, usually coarsely toothed. Largely southern species (except *P. sargentii*).

Pedicels as long as and usually longer than the capsules;[10] leaves lustrous above, thick. Fruit three- or four-valved; large trees.

Leaves glabrous, not cilate, usually broader than long, yellow-green, not pale beneath, abruptly short-pointed, coarsely and irregularly crenate-serrate but the tip often entire. Glands absent at base of leaf blade;[11] capsules 10–13 mm long; southwestern tree, Lower and Upper Sonoran Zones ..... *P. wislizeni*

Leaves ciliate but glabrous on both faces, deltoid or cordate-deltoid, about as long as broad or somewhat longer, crenately serrate with incurved glandular teeth. Buds glabrous, not resinous; floral bracts deciduous. Typically eastern tree, river bottoms and lowlands.

*P. deltoides virginiana* (=*P. virginiana*)[12]

Pedicels shorter than the capsules.[10]

Twigs slender; capsules not over 6 mm long.[13] Leaves truncate or broadly cuneate at the base, long-acuminate,

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[9] Dode (27) has separated out a form of this under the name of *P. hastata* Dode, which Mr. Sudworth here recognizes as *P. trichocarpa hastata* (Dode) Henry. Dode distinguished it by its larger catkins, larger, more acuminate, and less conspicuously nerved leaves, and glabrescent capsules. It seems to be a feebly separable form at best and Tidestrom rejects it altogether. Rydberg (71) separates it from *trichocarpa* on the following key (*N. B.*—Dode states that the petioles of *trichocarpa* are pubescent, and those of *hastata* pubescent when young):

Petioles usually more or less pubescent; ovary and capsule subglobose, densely pubescent ..... *P. trichocarpa*

Petioles glabrous; ovary and capsule ovoid, glabrous ..... *P. hastata*

Tidestrom regards the above characters as entirely too variable in this species to hold; it will be noted that he recognizes *trichocarpa* but makes no mention of *hastata* in his Flora of Utah and Nevada (93). Rydberg (71) admits typical *trichocarpa* to Montana and presumably to Idaho also. Sudworth, in this bulletin, does not admit any but the form *P. trichocarpa hastata* to the Rocky Mountains. The type locality of both *trichocarpa* and *hastata* seems to be California.

[10] Some botanists believe this character is too variable to hold.

[11] Willdenow first made use of this character, but later botanists (except Rehder) have largely discarded it as uncertain.

[12] Tidestrom questions western range (except under cultivation) of this typically eastern species or variety.

[13] Tidestrom is inclined to regard *arizonica* as a synonym of *P. fremontii*. It is supposed to have the smallest fruits among American cottonwoods (Sargent), but this raises questions of dwarfing and improper fertilization.

coarsely serrate, 3.5–5 cm long; disk cup shaped,[14] bark light gray and ridged or, on young trees, smooth. Good-sized tree, southwestern California to southern Arizona and northern Mexico ..... *P. arizonica*[13]

Twigs stout; capsules 8 mm long or more. Leaves truncate, subcordate or reniform at base.

Disk of pistillate flowers and capsules minute.[14] Leaves deltoid to broadly ovate, long-acuminate, truncate at base, coarsely serrate, 4–6 cm long; fruiting capsules 8 mm long, their pedicels 1.5–3 mm long; twigs glabrous ..... *P. texana*

Disk larger, cup shaped, 5–8 mm broad.[14] Leaves subcordate or reniform at base, varying to truncate.

Leaves usually about as broad as long or broader than long, coarsely serrate, short-acuminate, pubescent when young; glands absent from juncture of petiole and leaf blade.[15] Disk well developed, 6–8 mm broad,[14] capsules 8–11 mm long ..... *P. fremontii*[16]

Leaves usually longer than broad, long-slender-acuminate, coarsely crenate-dentate, glabrous, lustrous, thick, often varying to ovate; glands present at juncture of petiole and leaf blade.[15] Disk small, about 5 mm broad;[14] capsules about 10 mm long, on pedicels 2.5–3 mm long; winter buds puberulent; twigs light yellow ..... *P. sargentii*

## ASPEN (POPULUS TREMULOIDES MICHX. AND P. TREMULOIDES AUREA (TID.) DAN.)

### COMMON NAME AND EARLY HISTORY

In 1911 the American aspen, previously known solely as *Populus tremuloides* Michx., was definitely separated by Tidestrom (*92*) into an eastern and a western species. The eastern form retains the designation *P. tremuloides* Michx. and the western form is known as *P. tremuloides aurea* (Tid.) Dan. (*23*). Without reference to these systematic changes, both forms appear to be most widely known simply as aspen and less commonly under a variety of names, such as quaking asp, American aspen, poplar, trembling poplar, popple, and trembling aspen.

American aspen does not appear to have been distinguished from European aspen (*P. tremula* L.) until 1803, when the French botanist, André Michaux (*58*) described it as *P. tremuloides*.[17] It was

[14] Most botanists use disk characters in describing and separating poplars, but Tidestrom thinks it is very variable within the same species.

[15] Some botanists recognize these glands as good characters; others do not.

[16] Here belong Sargent's 4 varieties (recognized by Sudworth), viz: *macrodisca* (with long disks nearly enclosing fruit); *pubescens* (with pubescent twigs; typical forms of *fremontii* have glabrous twigs); *thornberi* (with shorter pedicels, smaller disks, narrower capsules, and more numerous marginal teeth on the leaves), and *toumeyi* (with large disks and long-pointed leaves shallowly cordate at base). The *Populus macdougalii* of this bulletin seems to key at once to *P. fremontii*. The pubescence of foliage and twigs in *P. macdougalii* is very variable and it tends to be glabrescent. While Standley recognizes it as a species (*83*), he says it is "probably not specifically distinct" from *P. fremontii*. Sargent (*79*) separates it from *P. fremontii* chiefly on the development of the disk, a factor which Tidestrom states is extremely variable. Tidestrom regards *P. macdougalii* as coalescent with *P. fremontii*, and has thus treated *macdougalii* as a synonym in the manuscript of his Flora of Arizona. Abrams (*2*) states that the characters used to distinguish *macdougalii* from *fremontii* "are not constant" and feels that "it is doubtful if the species is distinct."

[17] House (*42, p. 260*) has this interesting nomenclatural note on *Populus tremuloides* Michx.: "This tree was quite fully described long before Michaux's publication, by C. F. Ludwig (Neue Wilde Baumz. 35. 1783). In Darmstadt, Germany, I was able to consult this rare publication, and it appears that the plants described were sent to Germany from the German colony at Athens on the Hudson river, in this State, and the species was designated as *Populus athenensis*. The date of the publication is uncertain, but is supposed to be about 1783." W.A.D.

then known to occur abundantly in lower Canada and the Northern States. Eighteen years before this, in 1785, Humphrey Marshall (*57*) described this species as *P. tremula*, American aspen tree, showing that he believed it to be the same as the European aspen.[18]

*P. tremuloides* represents a somewhat variable species of extremely wide range, which in the 100 years and more since it became known to science has been traced from Labrador and Hudson Bay to Alaska, southward through Canada and over most of the United States (excepting the South Atlantic and Gulf States), and even into northern Mexico. To the ordinary observer, the characteristics now relied upon to separate the eastern and western forms of aspen will not be appreciated, because they are relatively trivial, relating chiefly to minor differences in the size and shape of the leaves and to differences in autumnal coloration. Silviculturally, a rational treatment would seem to be to consider both forms as one species, comprising two geographic forms.

As now understood, our American aspen is botanically separated into the following closely related forms: (1) *P. tremuloides* Michx. (in its typical form) and (2) *P. tremuloides reniformis* Tid., both mainly eastern forms; (3) *P. tremuloides aurea* (Tid.) Dan., a widely distributed western form; (4) *P. tremuloides cercidiphylla* (Britt.) Sudw. (*90*), a locally restricted form of western Wyoming (upper basin of the Hoback River); and (5) *P. tremuloides vancouveriana* (Trel.) Sarg., a form confined to the locality of Vancouver Island.

The fourth form was originally described (*19, p. 180*) in 1908 as a species, but its varietal relationship to the type species seems so obvious that it is here designated as *P. tremuloides cercidiphylla* (Britt.) Sudw. Two of these forms, *P. tremuloides aurea* and *P. tremuloides cercidiphylla*, occur within the Rocky Mountain region.

### DISTINGUISHING CHARACTERISTICS

The western form of the aspen attains a height ranging from 25 to 80 or 90 feet and a diameter from 6 to 30 or more inches. The smaller trees are common on the poor, thin, rocky soils of ridges and high mountain slopes, while the larger sizes are characteristic of the lower elevations in the richer soils of mountain coves and benches. In very high exposed places the growth is greatly stunted and characterized by bent or almost prostrate stems. In pure dense stands the large trees have straight trunks clear of branches for two thirds of their length. The short, slender, irregularly bent limbs stand out straight from the stems in a narrow domelike crown which is much shorter in dense than in open stands. The smooth firm trunk bark is conspicuously grayish white, brownish green, pale green, or varied with greenish or yellowish areas. It is irregularly furrowed and ridged only at the base of the trunk, where in larger

[18] The American aspen is said to have been first introduced into cultivation in England in 1779 by the Duke of Northumberland. The likeness of this tree to the European *P. tremula*, frequent in gardens, is probably the reason why the American aspen is so little seen abroad.

trees it is blackish and may be from 1 to nearly 2 inches thick. Many black rounded protuberances and curved scarlike marks are scattered over the smoother portions of the trunks.

The leaves (fig. 1), which are smooth at maturity on both surfaces, are somewhat shiny and deep yellow-green above and dull and much paler beneath.[19] The leaf stems are yellow and flattened near the leaf blade and range in length from about 1¼ to nearly 3 inches. In autumn the leaves become a clear golden yellow, sometimes orange or nearly red. Mature twigs are smooth and shiny, and are a clear reddish brown in autumn of the first year, later becoming pale reddish gray, and finally dull gray. For several years the twigs are

FIGURE 1.—Foliage of *Populus tremuloides aurea*. × ½.

rough with old leaf scars. The conical, smooth, shiny winter buds are reddish brown and thinly resinous.

The silvery white sapwood forms a large proportion of the stem. The small core of heartwood is pale brown. In general, the wood is rather fine grained, very soft, and brittle. It decays rapidly in contact with the ground. As it is practically odorless, the seasoned wood of fire-killed trees is much used for food containers, excelsior, pulp, and many other purposes. (*74*, *101*.) On account of their lightness, aspen logs, cut and peeled in the spring and air-dried for a season, have long been a favorite material for log houses.

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[19] *P. tremuloides cercidiphylla* (Britt.) Sudw. differs from the form under discussion in its shorter leafstalks, and its small, thick, redbudlike, slightly heart-shaped leaves, the margins of which are entire or inconspicuously wavy, and in which the lowest pair of veins are almost as long and as stout as the midvein. In addition, a peculiarly distinctive mark of this tree is a pair of minute, oblong, brownish, concave glands situated on the under side of the leaf at the base. This form was discovered by C. C. Curtis in August 1900.

OCCURRENCE AND HABITS

Aspen grows at widely varying altitudes over its extensive range (fig. 2). At the north it ranges from 1,000 up to 5,800 feet, and southward in the great mountain systems it may ascend to elevations ranging from 6,000 to 11,000 and occasionally 12,000 feet. As a rule, it is of small size at elevations above about 7,000 feet, and it becomes

FIGURE 2.—Geographic distribution of western forms of aspen.

more and more stunted as it reaches the wind-swept rocky slopes and ridges of upper levels. The largest and most perfect growth occurs on protected benches and lower slopes of mountains at elevations between about 3,000 and 6,000 feet or occasionally higher.

Aspen is naturally a forest-forming species and often covers immense areas with a dense pure stand. It is commonly the first tree to establish itself on fire-denuded lands. If seed trees of the original forest of pine, spruce, or fir have been completely killed off

over extensive areas, thick stands of aspen may continue to hold the ground for many years. But wherever seed trees of the original conifer forest survive, a scattered growth of pines, spruces, and firs soon invades the nearby thickets of aspen and ultimately crowds them out. Aspen is usually considered to represent a very transient type of forest which, because of its superabundant seed production and the ease with which the seed is carried long distances by wind, always comes in over large denuded areas. As scattered small areas of pure growth, it is often found in mixture with the longer-lived conifers of the region.

#### LONGEVITY

Height and diameter growth of aspen are most rapid during the period from 35 to 50 years of age. Merchantable size is attained at 50 years. Some trees maintain a vigorous condition up to as much as 120 years, after which they decline more or less rapidly, only occasional trees retaining their vigor to a maximum of 200 years. The average age limit is probably less than 150 years. Trees from 100 to 150 years old are from 11 to 15 inches in diameter and from 70 to 80 feet in height.

### BALSAM POPLAR (POPULUS BALSAMIFERA L.)

#### COMMON NAME AND EARLY HISTORY

Balsam poplar, sometimes also called balsam and incorrectly balm-of-Gilead—a name properly belonging to a variety of this species (*P. balsamifera candicans* (Ait.) A. Gray)—is distinguished in general appearance by its lustrous, very dark green leaves which, as they tremble and turn in the breeze, show glinting flashes of their pale-green and bright rust-brown under surfaces.

Balsam poplar has been for a great many years technically known as *P. balsamifera* L., which was established in 1753 (*54, v. 2*). Quite recently, however, some authors have come to believe that it is the "*P. balsamifera*" described by Du Roi (*29, v. 2*) in 1772, and not the *P. balsamifera* of Linnaeus that applies to the balsam poplar; they believe that *P. balsamifera* L. applies to the eastern form of cottonwood, variously designated as *P. monilifera* Ait. (*3, v. 3, p. 406*), *P. angulata* Ait. (*3, v. 3, p. 407*) and *P. deltoides* Marsh. (*57*). If this view is tenable, balsam poplar would be designated as *P. tacamahacca* Mill. (*59*), the next oldest name (1768) in its list of synonyms. However, the decision that the name *P. balsamifera* L. does not apply to the balsam poplar would seem to be an error, as proved by the fact that Linnaeus cites under his name Gmelin's description "POPULUS foliis ouatis, acutis serratis" in volume 1 of the latter's Flora Sibirica, page 152, plate 33, 1747 (*32, v. 1*). Gmelin's plate 33, cited by Linnaeus, clearly represents the foliage of our balsam poplar and in no way the deltoid foliage of our eastern cottonwood (*P. deltoides* Marsh. and *P. deltoides virginiana* (Castigl.) Sudw.). The writer is, therefore, here retaining *P. balsamifera* L. for the balsam poplar.

During the nearly 200 years that balsam poplar has been known to science, 3 or 4 varieties, mainly garden forms, have been segregated. Only one of these, *Populus balsamifera candicans* (Ait.) A.

Gray, described later, is of importance in this connection. Elwes (*30, p. 1833*) credits Aiton with the statement that balsam poplar was cultivated at Hampton Court in 1692, and was again introduced in 1731, when a tree was planted in the Chelsea Botanic Garden. He also gives Walker (1812) as authority for the first introduction of this species into Scotland, by seed from Canada, in 1768. Loudon's testimony (*56, v. 3, p. 1673*) on the first point is very similar. Aiton (*3, v. 3, p. 406*), however, gives the year of introduction into England as 1731 alone. At the present time the tree is said to be rarely cultivated in England, where it appears to have been almost entirely replaced by *P. balsamifera candicans*, the form usually grown now by English nurserymen.[20]

### DISTINGUISHING CHARACTERISTICS

Balsam poplar, one of the largest and most characteristic deciduous trees of the great northern forest regions is, at its best, from 80 to 100 feet in height and from 3 to sometimes 6 or more feet in diameter. Commonly, it is from 60 to 70 feet in height, and the trunk is from 30 to 40 inches through. Stems straight and clear of branches for 30 to 50 feet are not uncommon; the large thick limbs trend upward strongly and form a rather long, narrow, and irregular open crown. The bark of large trunks is slightly reddish gray and has regular deep furrows and wide ridges; that of the large limbs and of young trees is brownish gray, sometimes with a greenish shade, and smooth or more or less roughened by blackish protuberances. Year-old twigs are clear, shiny, and reddish brown, with conspicuously large chestnut-brown, pointed buds (fig. 3) which are from five eighths to nearly an inch in length. The bud scales are thickly coated with a yellowish, pungently fragrant balsam, with which the young leaves are also coated and from which the tree derived its common name. Mature leaves are slightly leathery, smooth, dark green, and shiny on the upper surface, and light green, whitish, or rust colored and very veiny on the under surface. They are usually about 3½ to 5 inches in length and about 2 to 3 inches in width. Leaf stems are round, smooth, and very slender, and are about 1¾ to 2 inches long.

Balsam poplar wood is light in weight, soft, rather narrow-ringed, and has a thick layer of nearly white sapwood. The heartwood is pale brown. In general appearance the wood of this poplar closely resembles that of other timber poplars and cottonwoods. The large trunks give clear wide lumber which is suitable for light packing boxes, slack-cooperage stock, and paper pulp.

### OCCURRENCE AND HABITS

Balsam poplar (fig. 4) forms small pure stands and is also more or less mixed in its northern reaches with black and white spruce, alpine and balsam fir, birch, alder, willow, aspen, and black cottonwood. It inhabits cool humid climates with short growing seasons and very low temperatures in winter, but rarely ascends to an

[20] The largest balsam poplar tree observed in Great Britain by Elwes (*30, p. 1833*) was 71 feet high and 7 feet 10 inches in circumference in 1905. Balsam poplar has been introduced into Norway, where it is said to thrive as far north as latitude 69°40′.

FIGURE 3.—Leaves and buds of *Populus balsamifera*. ×1.

elevation of more than 5,500 feet above sea level in the Rocky Mountain region. It grows naturally in alluvial stream bottoms, on flats, on moist benches which are often deep and rich, or on the borders of lakes and swamps in moist sandy and gravelly soils. In youth the balsam poplar is only moderately tolerant of shade; with age it becomes very intolerant. It sometimes reproduces itself in dense stands beneath the shade of old trees, but the young trees die out during the pole stage or earlier unless they receive full top light.

#### LONGEVITY

Balsam poplar grows very rapidly in height and diameter during the first 40 or 50 years of its life. It is not a long-lived tree, the

FIGURE 4.—Geographic distribution of balsam poplar (*Populus balsamifera*).

maximum age of full development being about 160 years. However, individual trees may remain alive to approximately 200 years.

### BALM-OF-GILEAD POPLAR (POPULUS BALSAMIFERA CANDICANS (AIT.) A. GRAY)

#### COMMON NAME AND EARLY HISTORY

Balm-of-Gilead poplar is often called balsam poplar, but the historically proper name for this variety seems to be the one here given.

There has long been doubt as to the natural range of this tree, a question which is not yet satisfactorily cleared up. From time to

time it was believed to be indigenous in the northeastern part of the United States and in eastern Canada. It is now thought to have been established in that region from cultivated trees, the origin of which is in doubt. As now known, the balm-of-Gilead poplar extends from Newfoundland to North Carolina and westward to Michigan, and possibly occurs, as some authors believe, even in South Dakota, Colorado, Alberta, and Alaska (fig 5).

The balm-of-Gilead poplar first became known to science in 1789, when it was technically described as a distinct species, *P. candicans* Ait. (*3*). It was possibly first described (in part) in 1768, some 21

FIGURE 5.—Geographic distribution of balm-of-Gilead poplar (*Populus balsamifera candicans*).

years earlier, as *P. tacamahacca* Mill. (*59*). Miller's description, however, seems to include also the balsam poplar. Still held to be a distinct species, the balm-of-Gilead poplar was 40 years later, in 1829, described as *P. macrophylla* Lindl. (in Loudon, *55*, *p. 840*) and as *P. ontariensis* Desf.[21] Lastly, in 1856, this poplar was held to be

[21] *Populus ontariensis* is not mentioned in Sargent's Silva (*76*, *v. 9*, *p. 14*), in Miss Day's card index, or in Dode's monograph (*27*). The Index Kewensis (*44*, *v. 3*, *p. 606*) cites "*Populus ontariensis* Lodd. ex. Loud. Arboret. 3. 1676." In Loudon's work referred to, however, *P. ontariensis* is given (*56*, *v. 3*, *p. 1676*) as a synonym of *P. candicans* Ait., Desfontaines as the author, and Hort. Par. as the place of publication. Furthermore, Elwes and Henry (*30*, *v. 7*, *p. 1834*) give the citation "*Populus ontariensis*, Desfontaines, Cat. Hort. Paris (1829)." I am unable to locate that name, however, in the U.S. Department of Agriculture Library copy of the work referred to (*26*). Alice C. Atwood states she has examined the second edition of this work of Desfontaines' and has not been able to find the name there.—W. A. D.

a variety of the balsam poplar and designated as *P. balsamifera candicans* (Ait.) A. Gray (*33, p. 419*), which, the writer believes, correctly expresses the identity of this tree. However, it is possible that future evidence may show that the balm-of-Gilead poplar is specifically distinct from the balsam poplar.

At the present time there is a confusion of judgment among authors as to whether both male and female trees exist in this country. The author has seen only the male trees here. Sargent (*76, v. 9, p. 126*) says only the pistillate tree is known. Dame and Brooks (*22, p. 37*) state that trees of both sexes have been found in New Hampshire and Vermont but that male trees are rarely if ever seen in southern New England.

Balm-of-Gilead poplar is said to have been introduced into England about 1772, where it has since been generally propagated for ornament (*3, 56*). It is preferred to balsam poplar because it can more readily be grown from cuttings. Only female trees appear to be used for this purpose.[22]

### DISTINGUISHING CHARACTERISTICS

Balm-of-Gilead poplar, comparable in height and diameter to balsam poplar, is characterized by a broader and more open crown and more spreading branches. It is generally distinguishable also by larger, broader, more ovate-cordate leaves, which are 5 or 6 inches long and about 4 inches wide at the base, by its pubescent leafstalks (petioles), and perhaps by a stronger fringe of minute hairs on the leaf margins and on the smaller veins on the lower surfaces of the blades.

The wood is very similar in general appearance to that of balsam poplar but is somewhat heavier. No special use is made of the wood, although it would be suitable for the same purposes as balsam poplar.

### OCCURRENCE AND HABITS

Balm-of-Gilead poplar is apparently very like balsam poplar in its habitat. It occurs in moist soils, either as single individuals or in small groups interspersed with native trees.

### LONGEVITY

Balm-of-Gilead poplar grows very rapidly in height and diameter during the first 35 or 40 years. It attains maximum development in about 50 years but continues to live long afterward. Little is known of its age limits, but the greatest age probably does not exceed 150 to 175 years.

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[22] According to Elwes (*30, p. 1835*) nearly all the balsam poplar trees in England are of this variety. The largest specimen seen by him was at Syon and at that time (1906) was 85 feet high and nearly 3 feet in diameter. Numerous other specimens growing in England, observed in 1910, averaged not more than 70 feet in height and about 2 feet in diameter. Henry (*30, p. 1834*) reports an unnamed form of this poplar, apparently of garden origin, having the leaves blotched with yellow, specimens of which may be seen at Woburn, and in the Glasnevin and Edinburgh Botanic Gardens.

## NORTHERN BLACK COTTONWOOD (POPULUS TRICHOCARPA HASTATA (DODE) HENRY)

### COMMON NAME AND EARLY HISTORY

Northern black cottonwood, sometimes also called balsam cottonwood and black balsam poplar, extends over a wide range from Alaska through British Columbia to southern California and eastward into the Rocky Mountain region. *P. trichocarpa* (black cottonwood) was first described by Torrey and Gray (ex Hooker, (*40*)) [23] in 1852, based on specimens collected by C. C. Parry in 1850 on the Santa Clara River, near Buena Ventura, Calif. Although generally it has been clearly understood, some forms have been somewhat confused with its near relative the balsam poplar, which it closely resembles. In 1905 a form of northern black cottonwood with large pointed leaves with rounded or heart-shaped bases was described as *P. hastata* Dode (*27*); this is clearly not specifically distinct but is properly to be considered a variety of *P. trichocarpa hastata* (Dode) Henry (*30, p. 1837*). This form of the northern black cottonwood is the typical form of the species in the Rocky Mountain region.

The earliest record of the northern black cottonwood is found in the narrative of the Lewis and Clark Expedition (*53*), where mention is made of the occurrence of this tree near the mouth of the Columbia River, in all probability the *P. trichocarpa hastata* (Dode) Henry of the Rockies. What is probably the same variety was introduced into cultivation in continental Europe in 1889 from seed obtained in British Columbia, and into England in 1892.[24]

### DISTINGUISHING CHARACTERISTICS

In the Puget Sound country, the region of the greatest development of northern black cottonwood in North America, this tree attains a maximum height of 200 feet and a diameter of 6 or 8 feet. Within the Rocky Mountain region its greatest size is considerably less. Its straight or sometimes slightly bent trunk is commonly clear of branches to a height of 60 to 80 or more feet. The pale gray trunk bark is regularly, deeply, and sharply furrowed and is from 1 to 2½ inches thick. Trees grown from the first in the open have broad oval-shaped crowns, but the crown of forest-grown trees is open, short, and wide. Twigs when young are indistinctly angled; later they become rounded, shiny, and reddish yellow or brownish, and finally grayish, when they are much roughened by the thickening leaf scars. The reddish or orange-brown winter buds, which are from five eighths to three fourths of an inch long, are curved, as if bent above the middle. They are covered with a yellowish-brown fragrant gum similar to that found on the balsam poplar; the presence of this gum has led to frequent confusion of the two trees. Mature leaves (fig. 6) are thick, leathery, and smooth, deep shiny

[23] The Check List (*90, p. 63*) cites Hooker as the author of *Populus trichocarpa,* but Hooker himself (*40*) cites Torrey and Gray as the authors of the species.—W. A. D.

[24] According to Elwes (*30, p. 1837*), the oldest tree known was planted in the Edinburgh Botanic Garden in 1892. In 1906 this tree was 39 feet in height and nearly 10 inches in diameter. The largest tree at the Kew Botanic Gardens, obtained from Späth in 1896, was, in 1911, 55 feet high and a little less than 15 inches in diameter.

green on the upper surface and on the lower surface very veiny and silvery white, or whitish with rusty areas. On the under side of the leaf the midveins and their branches are minutely hairy—rarely smooth. Distinguishing characteristics of the leaves of this varietal form, as contrasted with those of the species, are their greater thick-

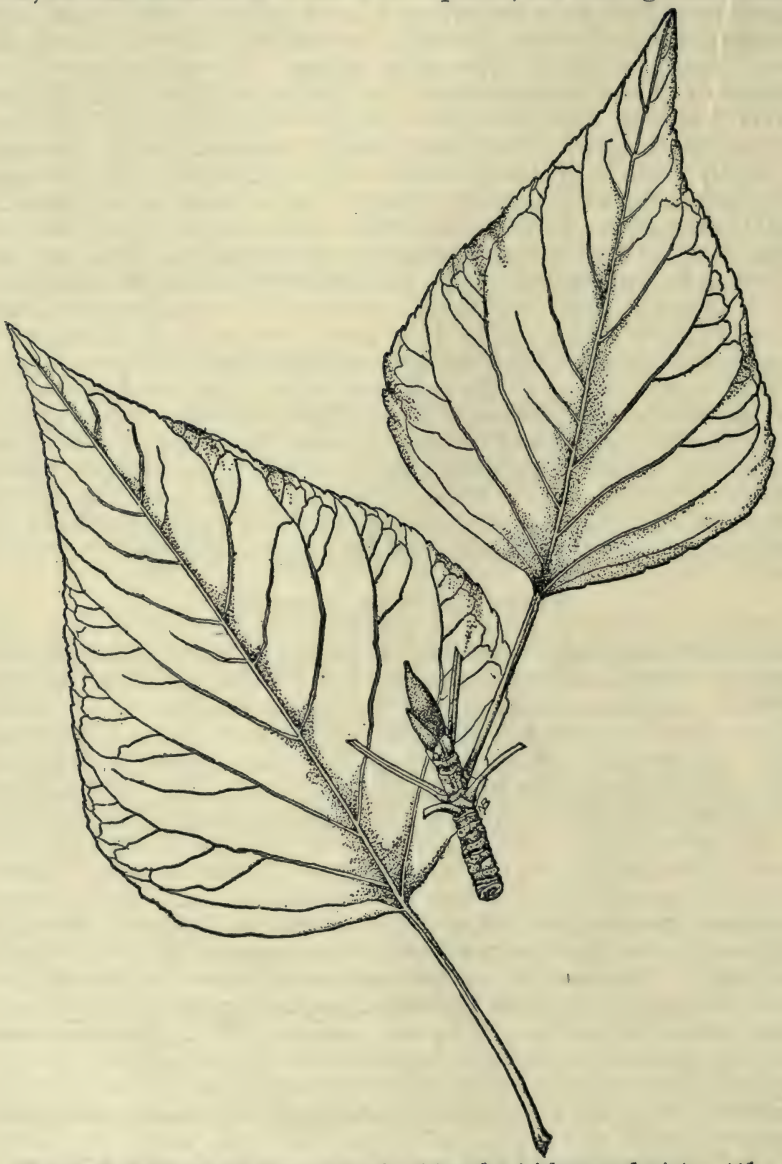

FIGURE 6.—Foliage and portion of twig of *Populus trichocarpa hastata*. ×1.

ness, more leathery texture, larger size (often from 5 to 6 inches in length and 3 to 4 inches in width), rounded or rarely heart-shaped bases, and long points (leaves of the species are commonly very short pointed). The slender, rounded leafstalks and very young

twigs are mostly hairless, whereas in the typical forms of the species those parts are usually more or less hairy.

Trees grown in a dense stand have narrow-ringed wood with a relatively thin layer of whitish sapwood and dull grayish-brown heartwood. Large logs obtainable from the best-grown trees give wide, clear lumber. The wood when thoroughly seasoned is soft, straight grained, and odorless and is suitable for food containers,

FIGURE 7.—Geographic distribution of black cottonwood (*Populus trichocarpa*) and northern black cottonwood (*P. trichocarpa hastata*), the more common variety appearing outside of the heavy line.

excelsior, cheap lumber, and tight cooperage. Large quantities have been used in Oregon and Washington for apple and sugar barrels. The wood has already been used to a considerable extent for paper pulp.

### OCCURRENCE AND HABITS

Northern black cottonwood (fig. 7) grows most extensively at low elevations in river bottoms, on sand bars, and along watercourses in sandy, rich, humus soils. In the last-named locations it reaches

its largest size. It is less abundant and smaller at higher elevations, where it grows in canyon bottoms and gulches in moist sandy or gravelly soils, and in drier atmospheres where there is much less soil moisture. The climate in the region of its best growth is marked by great humidity, abundant precipitation, and moderate temperatures. Under the best conditions this variety forms broad belts and smaller areas of pure growth and in some places also occurs in mixture with other broad-leaved trees and conifers of its range. It is very intolerant of shade throughout life. Rapid height growth during the first 40 or 50 years enables it to hold its own in mixture with much more shade-tolerant conifers, among which its small crown is carried high into full light.

#### LONGEVITY

The age limit of northern black cottonwood has not been fully determined. It is, however, comparatively short-lived, like its near relatives. Probably the largest trees (the sort now mostly cut for lumber) are between 150 and 200 years old, possibly more. Trees from 2 to 3 feet in diameter are from 85 to 110 years old; one tree measuring 43½ inches in diameter was 112 years old.

### LANCELEAF COTTONWOOD (POPULUS ACUMINATA RYDB.)

#### COMMON NAME AND EARLY HISTORY

The lanceleaf cottonwood, also called cottonwood, Rydberg's cottonwood, and smoothbark cottonwood, was for a long time not distinguished from the narrowleaf cottonwood (*P. angustifolia* James), which it somewhat resembles in general appearance. It was first described in 1893 by Rydberg (*68, p. 46*), who in 1891 discovered a grove of over 100 trees in Carter Canyon, Scotts Bluff County, northwestern Nebraska. Sargent, however, states (*76, vol. 4*) that he has seen in Engelmann's herbarium a specimen of this cottonwood collected by Hayden on the Reynolds expedition to the headwaters of the Missouri and Yellowstone Rivers in 1859–60. He further states that Engelmann collected it in 1874 at Denver, Colo., and that he himself found it in 1880 in Colorado Springs.

#### DISTINGUISHING CHARACTERISTICS

Lanceleaf cottonwood, which grows from 35 to 40 feet high and from 10 to 20 inches in diameter, has a dense rounded crown made up of robust branches, the lower of which are spreading whereas the upper trend upward rather sharply. Bark of larger trunks, approximately one half an inch thick, is light grayish brown and broken into narrow furrows and wide flat ridges. Bark of young trees and of the large limbs of old trees is smooth and whitish. The smooth, slender, rounded or somewhat quadrangular twigs are pale yellow-brown and marked for several years by the old leaf scars. Mature terminal buds, approximately one half of an inch long, are shiny, cinnamon brown, and more or less gummy; lateral buds are smaller and flattened against the twig. Mature leaves (fig. 8), 2 to 4 inches in length and from three fourths of an inch to as much as 2 inches in width, are pendulous (being borne on slender, nearly

round stems) and thickish and leathery. They are of a deep glossy green on the upper surface and dull green on the under surface; the slender midvein and its branches are light yellow. The slender drooping fruiting catkins are from 4 to 5 inches long, and the smooth rather short-stalked capsules are about one third of an inch long.

Wood of the lanceleaf cottonwood is very similar in its light weight and soft texture to that of *Populus angustifolia* James; the

FIGURE 8.—Spray of *Populus acuminata*. ×1.

thin layer of sapwood (showing 12 to 28 annual rings) is grayish white, and the heartwood is pale yellowish brown. Because of the small size of the tree only occasional use is made of the wood, viz, for temporary fence posts and corral poles.

### OCCURRENCE AND HABITS

Lanceleaf cottonwood (fig. 9) grows rather sparingly along streams, in moist, poor, sandy and rocky soils, usually in small groups or as scattered individuals. In general, its habitat is rather arid regions. It is very intolerant of shade, apparently in all stages of growth.

### LONGEVITY

Lanceleaf cottonwood appears to be short-lived but of rather rapid growth. A log cut in northwestern Nebraska and measuring

FIGURE 9.—Geographic distribution of lanceleaf cottonwood (*Populus acuminata*).

about 13 inches in diameter is from a tree but 28 years old (*76, v. 14, p. 69*). This diameter growth probably represented a height of 35 to 40 feet.

### POPULUS ACUMINATA REHDERI SARG.

This variety of the lanceleaf cottonwood differs from the species in its larger leaves, longer leafstalks, and hairy twigs and mature buds. So far as is now known it is confined to southeastern New

Mexico, where it occurs along watercourses. (See area covered by grille, fig. 9.)

#### X POPULUS ANDREWSII SARG.

This is supposed to be a natural hybrid between *P. acuminata* Rydb. and *P. sargentii* Dode, and in it the characteristics of both these trees appear to be more or less combined. It grows in a wild state in the vicinity of Boulder and Walsenburg, Colo. (see solid black area, fig. 9), and is planted in the streets of Montrose, Colo. (*79, p. 129*).

### NARROWLEAF COTTONWOOD (POPULUS ANGUSTIFOLIA JAMES)

#### COMMON NAME AND EARLY HISTORY

Narrowleaf cottonwood, also called black cottonwood, willow cottonwood, willow-leaved cottonwood, and bitter cottonwood, first became known to science in 1823 under the technical name *P. angustifolia* James (*45*). Edwin James, the author of this name, discovered the tree in Colorado. Record of what is doubtless the original discovery of this cottonwood is to be found in the narrative of the expedition made across the continent in 1804–6, under the command of Captains Lewis and Clark.[25] (*53, v. 1, pp. 330–338.*)

During the upwards of 100 years since this cottonwood became known to science, its distinctly willowlike leaves have prevented its confusion with any other cottonwood of the West, except, perhaps, *P. acuminata.* Rafinesque, evidently not knowing it had been described, named it *Populus salicifolia* in 1838 (*62*). Thirty years later (1868) it was designated as *P. canadensis*, γ *angustifolia* Wesmael (*102*), and again in 1871, as *P. balsamifera*, var. *angustifolia* S. Wats. (*98*).

#### DISTINGUISHING CHARACTERISTICS

Narrowleaf cottonwood attains a height ranging from 40 to 60 feet and a diameter ranging from 12 to about 18 inches. In general appearance it is fairly distinct from other American cottonwoods, except the lanceleaf cottonwood, on account of its narrow willowlike leaves which give the crown a comparatively thin-foliaged aspect. The crown is narrowly pyramidal in outline, being composed of slender branches which trend sharply upward. The bark is usually about 1 inch thick; that of the larger trunks, most of which are straight and free from branches for one fourth to one half their length, is light grayish brown and broken into shallow grooves and wide, flat-faced ridges at the base of the stem. Higher up on younger portions of old trees and also on young trees the bark is smooth, unbroken, and pale grayish green tinged with yellow. The slender twigs of a season's growth are smooth or very rarely hairy.

[25] On June 6, 1805, the expedition while traveling along the Tansy River, now known as the Teton River, tributary to the Upper Missouri River, came upon "a species of cottonwood, with a leaf like that of the wild cherry." Later, on June 12, members of the expedition observed that "with the broad-leafed cottonwood, which has formed the principal timber of the Missouri, is here mixed another species differing from the first only in the narrowness of its leaf and the greater thickness of its bark. The leaf is long, oval, acutely pointed, about two and a half or three inches long and from three quarters of an inch to an inch in width; it is smooth and thick, sometimes slightly grooved or channeled, with the margin a little serrate, the upper disk of a common, the lower of a whitish green. This species seems to be preferred by the beaver to the broad-leaved, probably because the former affords a deeper and softer bark."

At first they are pale yellowish green, but later they turn dark brownish red or orange; during the second season they become light yellow, and finally pale gray. The rounded, long-pointed terminal buds are from about one fourth to one half an inch long and are made up of resinous scales, strongly balsamic in odor and externally

FIGURE 10.—Sprays of *Populus angustifolia*. ×1.

chestnut brown in color. The lateral buds, which are from one eighth to one fourth of an inch long, are flattened on the side next to the twigs. Mature leaves (fig. 10) are rather thin but firm in texture. They are smooth and yellowish green on the upper surface, and smooth (or rarely hairy) and pale yellow green on the under surface. The margins are somewhat thickened and slightly turned

downward. The leaves range in length from about 1¾ to 6 inches and in width from about three fourths of an inch to 1½ inches. The leaves on young shoots are often 6 inches long or perhaps even longer and about 1½ inches wide. The leaf stems are short, slender, and slightly flattened on the upper side. The midrib is broad and yellowish, as are its main branches. The smooth pendulous fruiting catkins are about 2½ to 4 inches in length, their two-valved capsules being broadly ovate and suddenly contracted at the apex.

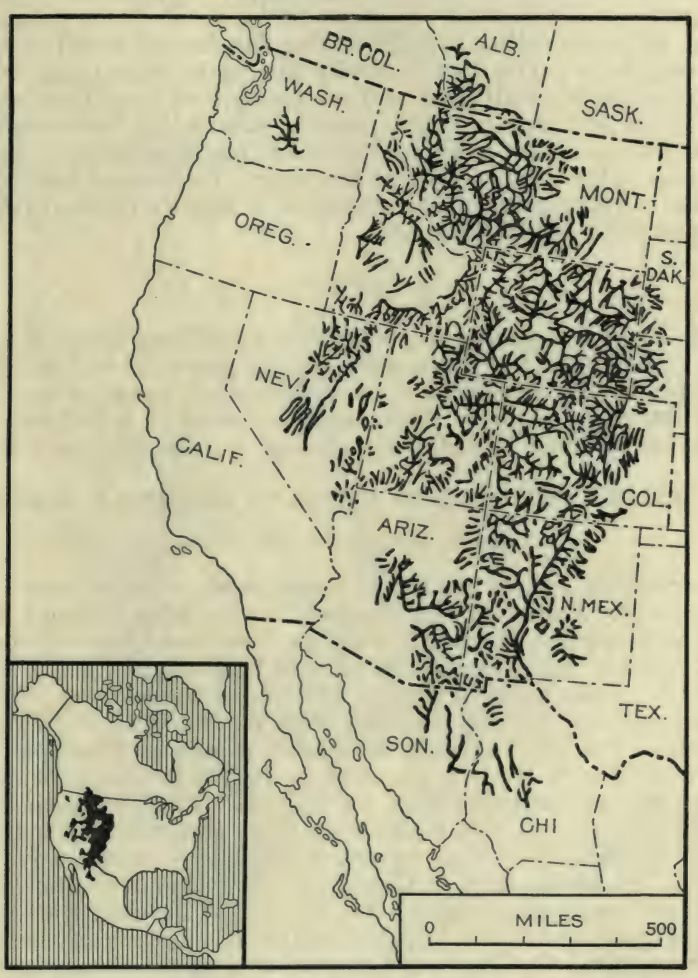


FIGURE 11.—Geographic distribution of narrowleaf cottonwood (*Populus angustifolia*).

Thoroughly seasoned wood weighs approximately 24 pounds a cubic foot. It is soft and brittle; the thin layer of sapwood (containing from 12 to 30 annual rings) is whitish and the heartwood pale brown. It is very similar in texture to the wood of lanceleaf cottonwood. Sometimes it is used locally for temporary fence posts or corral poles and occasionally for fuel.

#### OCCURRENCE AND HABITS

Narrowleaf cottonwood (fig. 11) grows singly or in groups scattered along the moist borders of mountain streams or flats at elevations ranging from 4,800 to 9,000 feet or more above sea level. It is rather more abundant in the central Rocky Mountain region than elsewhere in its range. The largest trees are usually found at elevations between 5,000 and 8,000 feet, sometimes in association with willows, mountain alder, scattered alpine fir, Engelmann spruce, and blue spruce. Narrowleaf cottonwood is decidedly intolerant of shade. It grows rather rapidly during the first 40 or 50 years.

Because it is native to the Rocky Mountain region and adapted to local climatic conditions, and on account of its attractive form and foliage and rather rapid growth, narrowleaf cottonwood has became a favorite for street and roadside planting in many parts of that area. However, at least at the lower elevations where rainfall is rather scanty, more or less irrigation is usually necessary for the tree to develop satisfactorily.[26]

#### LONGEVITY

Narrowleaf cottonwood is a relatively short-lived tree. It reaches its maximum height and diameter growth probably within 50 or 60 years, but it may remain in a sound condition, growing slowly, for 100 to 150 years or more. An authentic record of a tree cut on the Humboldt National Forest, Nev., showed it to be 130 years old.

### ARIZONA COTTONWOOD (POPULUS ARIZONICA SARG.)

#### COMMON NAME AND EARLY HISTORY

*P. arizonica* has no popularly established common name, being known locally simply as "cottonwood." The name Arizona cottonwood here applied is coined from the botanical name of the tree. Until recently, the Arizona cottonwood had not been satisfactorily classified. Prior to 1902 (*76, v. 14*) and subsequent to 1875 (*99*) Arizona cottonwood was confused with *P. fremontii* S. Wats.; for the next 17 years it was believed to be *P. mexicana* Wesm., a cottonwood of northern Mexico, described in 1868 (*102*), from which our cottonwood is now believed to be distinct. The status of Arizona cottonwood was, in the writer's opinion, satisfactorily settled in 1919 by Sargent, who characterized it as *Populus arizonica* (*78, pt. 4, p. 210*). Its main range in the United States, as now known, is in central and southern Arizona. On account of the long confusion of Arizona cottonwood with other closely related species of the Southwest it is difficult to determine just when and where it was discovered, but it is believed that Jean Luis Berlandier first found the tree in northern Mexico.[27]

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[26] According to Henry (*30, p. 1832*) this species scarcely attains more than shrub size in England, where, in Kew Gardens, it forms a small, irregularly spreading tree. He quotes Späth's Catalogue (Berlin 1893–94) to the effect that Späth introduced young Colorado plants of this species into Germany in 1893, but no information is given regarding their behavior.

[27] A variety of the Arizona cottonwood, *P. arizonica jonesii* Sarg., occurs in northern Mexico.

DISTINGUISHING CHARACTERISTICS

Arizona cottonwood ordinarily ranges in height from 35 to 50 feet but sometimes attains a height of 65 to 70 feet. The diameter is from 20 to 30 inches. The bark of larger trunks, from 1 to nearly

FIGURE 12.—Foliage and seed capsules of *Populus arizonica*. ×⅜.

1½ inches thick, is light ash-gray or sometimes whitish in color, and is broken into deep furrows and wide flat ridges. The bark of large limbs and young trunks is usually unbroken, smooth, and of an

ash-gray color. This is a rather short-trunked tree, with a broad, rounded crown of wide-spreading large branches. Most of the branches of young trees have an upward trend, whereas in old trees the large lower-crown branches (owing to their weight) are more spreading in their habit, though the upper-crown branches preserve a more upward trend. The slender twigs, smooth and pale yellow at the end of a season's growth, are more or less drooping. Terminal buds, which are approximately one fourth of an inch long, are pale reddish yellow or orange-brown, pointed, smooth, and slightly hairy near the base; the flattened lateral buds are very much smaller. Mature leaves (fig. 12), somewhat leathery in texture, are yellowish

FIGURE 13.—Geographic distribution of Arizona cottonwood (*Populus arizonica*).

green in color (very glossy on the upper surface and slightly paler beneath) and are from about 1½ to 2 inches in length. They have slender yellow midveins. The leaf stems, which are from 3½ to 4 inches in length, are smooth and laterally flattened; the leaves, which are borne by vigorous shoots, are often 2 inches long and nearly 3 inches wide. Mature clusters of seed capsules (fig. 12) are about 3 inches long. The thin-walled capsules are about one fourth of an inch long, pale yellow-brown, deeply marked with pits, and on elevated pedicels of about the same length.

Thoroughly seasoned wood of this cottonwood weighs approximately 28 pounds a cubic foot. The thin layer of sapwood is nearly white, and the heartwood is pale brown. Locally the wood is sometimes used for corral poles, posts, fence posts, roof timbers of adobe houses, and fuel.

#### OCCURRENCE AND HABITS

Arizona cottonwood (fig. 13) grows scatteringly along the borders of mountain streams in moist rocky or gravelly soils where the water flow is constant, and sometimes on the borders of dry stream beds which carry torrential waters at certain periods of the year, leaving the substrata continually moist. The trees occur singly, in a thin bordering line, or sometimes in scattered small and large groups; rarely is the growth of any considerable extent. This species gives evidence of being considerably more tolerant of shade than other cottonwoods of the Southwest, especially during its early stages of development.

#### LONGEVITY

This species grows rather rapidly up to an age of 30 or 40 years; thereafter growth is slower as is evidenced by the narrow annual rings in the sapwood. The maximum age is possibly between 100 and 150 years. Several trees freshly cut by beavers along Salt River, in Arizona, showed very rapid early growth, trunks from 12 to 20 inches in diameter being only from 16 to 27 years old.

### COTTONWOOD (POPULUS SPP.)

Under the common name of cottonwood are grouped four species and several varieties that have no other definite, well-recognized common name. These are *P. sargentii* Dode, *P. fremontii* S. Wats., *P. texana* Sarg., and *P. wislizeni* (S. Wats.) Sarg. *P. deltoides virginiana* (Castigl.) Sudw. and *P. macdougalii* Rose are generally known simply as cottonwood, but are described in the following pages under the common names of southern and MacDougal cottonwood.

#### POPULUS SARGENTII DODE

#### COMMON NAME AND EARLY HISTORY

This species has not acquired a distinctive common name; several coined or book names have been applied to it, such as "Sargent cottonwood", "western cottonwood", and "river cottonwood." The first name is coined from the present technical name of the tree, and the second is similarly derived from the third term of another of its scientific names, *P. deltoides occidentalis* Rydb.

Because of the early confusion of this species with several other cottonwoods growing within the region east of the Rocky Mountains, it is impossible now to find any very early authentic record of where or when the tree was discovered. It was first definitely characterized in 1900 as *P. deltoides* var. *occidentalis* Rydb. (*69*), and in 1905 it was designated as *P. sargentii* Dode (*27*); a year later (1906) it was renamed *P. occidentalis* (Rydb.) Britt. (*94*). Although this name is based on the oldest technical name applied to the tree, it must give way, according to the rule of nomenclature, to the oldest binomial applied, *P. sargentii* Dode.

DISTINGUISHING CHARACTERISTICS

In general appearance *P. sargentii* closely resembles *P. deltoides virginiana* (Foug.) Sudw. (p. 41), with which, among other eastern cottonwoods, it was long confused. As a rule it is a somewhat smaller tree, ordinarily ranging in height from 50 to 75 feet

FIGURE 14.—Foliage and seed capsules of *Populus sargentii*. ×⅞.

but less commonly reaching heights of 80 or 90 feet. Diameters range from 2 or 3 feet to from 4 to 6 feet. The trunk bark of fairly large trees is thick, externally gray, deeply furrowed, and ridged. On large branches and young trunks the bark is smooth or only

shallowly furrowed and is grayish. The straw-colored twigs are rounded or slightly angled and rough, with enlarged leaf scars. The pointed terminal buds are brownish yellow and slightly hairy. Mature leaves (fig. 14) are firm, smooth, light yellow-green and shiny on the upper surface and pale green on the lower surface. They are from 1½ to 3½ inches long and from 1¾ to 4 inches wide. The midrib and leaf stem are slender. The leaf stem is flattened and

FIGURE 15.—Geographic distribution of cottonwood (*Populus sargentii*).

from 2¼ to 3½ inches long; often two small glands are at its juncture with the leaf blade. The staminate flowers are borne in catkins from 1¾ to 2¾ inches long; pistillate flowers, borne in similar clusters, are from 3½ to 7½ inches long. The bluntly pointed smooth seed capsules, about two fifths of an inch long, are borne on tiny short pedicels, which are much shorter than the capsules (fig. 14).

Little is known now of the distinguishing characteristics of the wood. The heartwood is dark yellowish brown and the thick sap-

wood is nearly white. Locally the wood is sometimes used for temporary fence posts and corral poles and for fuel. In recent years it has been used rather extensively in Colorado for making veneer baskets for fruits and vegetables.

#### OCCURRENCE AND HABITS

*P. sargentii* (fig. 15) grows naturally in low moist ground in the vicinity of streams, where it may form a thin fringe, or in broad river bottoms in scattered pure stands. It is intolerant of shade during all stages of its growth. It is frequently planted as a shade tree in the streets of small towns within its natural range. It is essentially a stream-bank tree and is seldom found above an altitude of 7,000 feet.

#### LONGEVITY

This is a short-lived tree, usually attaining its maximum height and diameter growth within about 50 years, although under favorable circumstances it may remain in a vigorous condition for 80 to 90 years. During the first 25 or 30 years it grows rather rapidly to a height of some 40 or 50 feet and a diameter of 16 to 20 inches.

### POPULUS FREMONTII S. WATS.

#### COMMON NAME AND EARLY HISTORY

It is the writer's opinion that typical *P. fremontii* (*99, p. 350*) occurs solely within California and Baja California, and that it is replaced in the southern part of the Rocky Mountain region by four rather distinct varieties. For many years what is now known as *P. sargentii* was confused with *P. fremontii*, and it was supposed that the now clearly distinguishable *P. wislizeni* of western Texas, New Mexico, the Rio Grande region, and adjacent Mexico was varietally related. A careful study of the flowers and fruits of these poplars has disclosed distinctive characteristics. Although *P. fremontii* has been allowed no distinctive common name in the Check List, the name of Frémont cottonwood has been applied to it by several writers.

#### DISTINGUISHING CHARACTERISTICS

*P. fremontii* (fig. 16) ranges in height from 50 to occasionally 100 feet and in diameter from 1½ to sometimes 4 feet. The trunk, free from branches for about half its length, is rarely straight, but is more or less bowed and leaning. The thick branches and their drooping twigs form a wide, round-topped, open crown. The rough, thick, deeply furrowed bark is dark grayish brown without and clear red within; the wide distinctly cut main ridges are connected irregularly by smaller lateral ridges. Bark of large limbs and of young trunks is only slightly seamed and of a pale ashy brown color. Twigs of one season's growth are smooth and pale yellow; they become yellowish gray as they grow older. The shiny winter buds are greenish, the terminal ones, about one half of an inch long, being much larger than the lateral buds. Mature leaves are smooth throughout, rather thick and leathery, clear yellow-green and shiny, with flattened yel-

low stems. The leaves vary in length from about 2 to 2¾ inches and in width from 2¼ to about 3 inches; the leaf stems are from 1½ to sometimes 3 inches long. In the fall the leaves become a bright lemon yellow. The staminate flowers are borne thickly on a smooth

FIGURE 16.—Leafy twigs and fruit of *Populus fremontii*. ×⅛.

stem 1½ to 2¼ inches long, and the thinly flowered pistillate clusters are often from 3½ to 5 inches long by the time the seed capsules mature; the blunt or pointed seed capsules, about one half of an inch long, are sparingly pitted and borne on thick pedicels.

The wood of *P. fremontii* is pale dull brown, with a thin layer of whitish sapwood. It is considerably heavier than that of other cottonwoods and is rather coarse grained, soft, and brittle. It is not durable and is specially liable to crack in seasoning. It is not used commercially, but locally some use is made of it for fuel, temporary fence posts, and log buildings.

FIGURE 17.—Geographic distribution of cottonwood: 1, *Populus fremontii*; 2, *P. fremontii thornberii*; 3, *P. fremontii pubescens*; 4, *P. fremontii toumeyi*; 5, *P. fremontii macrodisca*.

### OCCURRENCE AND HABITS

*P. fremontii* (fig. 17) occurs exclusively in stream bottoms and along their borders, in moist, sandy, gravelly humus soils. It grows in a climate of high temperatures and low precipitation, where the air is generally dry except where rendered humid through the proximity and influence of the sea. The tree forms strips and small bodies of pure growth along the borders of streams or occurs in mixture with Arizona sycamore, willows, and alders. It is very intolerant of shade through life. It reproduces itself abundantly

from seed lodged in open moist soil or in sand and gravel. Sometimes it is planted along streets for shade. More recently it has been used in erosion-control operations.

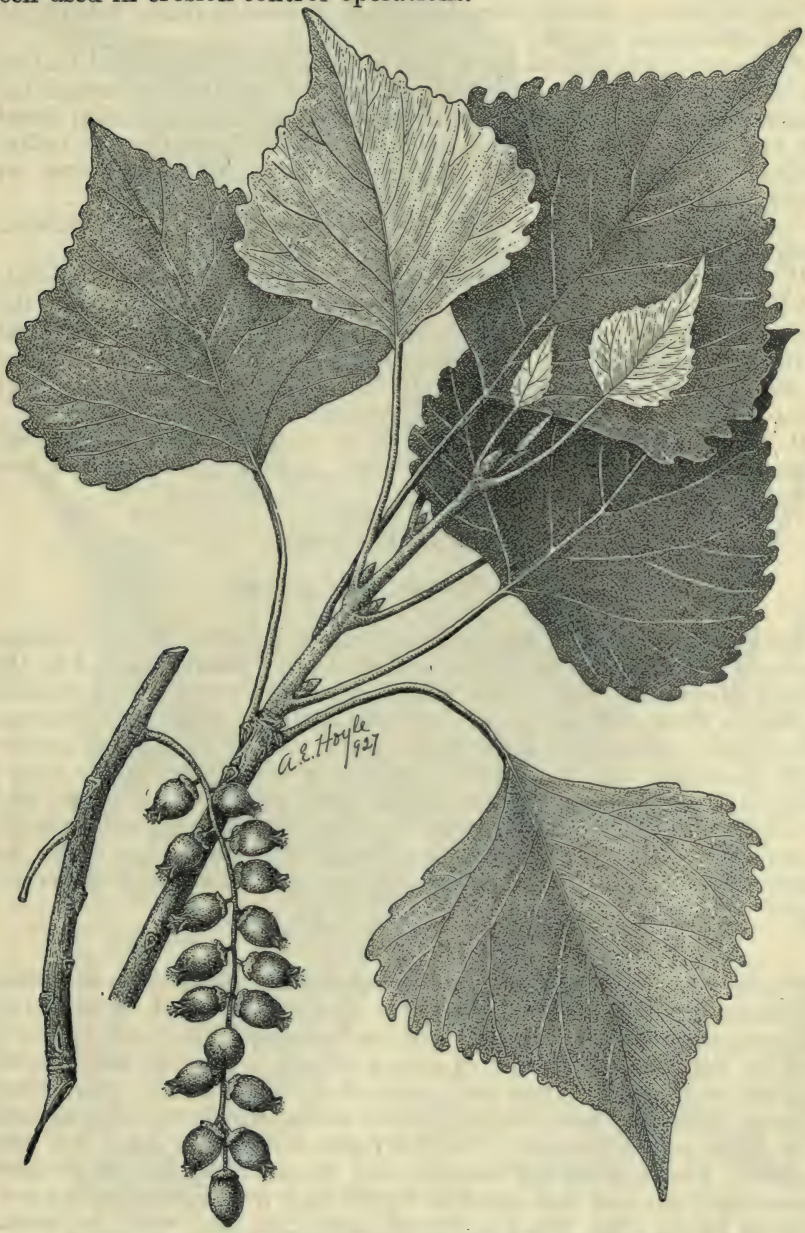


FIGURE 18.—Leafy twig and fruit of *Populus fremontii toumeyi*. × ⅝

LONGEVITY

*P. fremontii* appears to be short-lived. It grows rapidly to maturity, which it probably attains within about 50 years although

it may remain vigorous for a much longer time. One tree 36¼ inches in diameter (inside the bark) showed an age of only 29 years.

The following distinct varieties of *P. fremontii* occur within the Rocky Mountain region:

*P. fremontii thornberii* Sarg. (*78, pt. 4, p. 213*) is distinguished by the much more numerous teeth on the borders of the leaves and the elliptical shape of the seed capsules, which also have a smaller basal cup and shorter pedicels than the species whose capsules are rather distinctly ovate, with larger cup-shaped bases, and are borne on longer pedicels.

*P. fremontii pubescens* Sarg. (*78, pt. 4, p. 213*) is distinguished from the species by its hairy twigs.

*P. fremontii toumeyi* Sarg. (*78, pt. 4, p. 214*) (fig. 18) is distinguished from the species by the shallowly heart-shaped bases of the leaves, which are narrowed and wedge-shaped toward the attachment of the leaf stems. The leaves also are long pointed, whereas those of the species are rather squarely cut off at the base and short pointed. The seed capsules of this variety have large basal cups.

*P. fremontii macrodisca* Sarg. (*78, pt. 5, p. 62*) is distinguished from the species by the very large basal cups which nearly enclose the elliptical-shaped seed capsules.

### POPULUS TEXANA SARG.

#### COMMON NAME AND EARLY HISTORY

Little is known of *P. texana* Sarg., but it is included here because it occurs within a territory that is climatically closely related to the Rocky Mountain region. It was first satisfactorily distinguished in March 1919 (*78, pt. 4, p. 211*), the earliest authentic specimens having been collected in July 1917. Until 1919 *P. texana* was apparently confused with *P. wislizeni*, which it closely resembles in the shape and texture of its leaves, size and color of its twigs, and in its smooth buds. It is, however, readily distinguished from *P. wislizeni* by its much smaller seed capsules, which are borne on shorter pedicels. The ranges of the two species are also different.

#### DISTINGUISHING CHARACTERISTICS

*P. texana* is from 30 to 60 feet in height and from 12 to 30 inches in diameter. The bark on the lower part of the trunk is of a dull ash-gray color and is distinctly cut into narrow ridges and furrows; bark of the large limbs and of young trunks is grayish and smooth or little broken. The tree has a rounded, rather broad open crown of large drooping branches and stout twigs, which are smooth and of a light yellow-brown. The sharp-pointed winter buds are also smooth. Young trees are straight and symmetrical, but large specimens have more or less crooked trunks and unsymmetrical crowns. Mature leaves (fig. 19) are smooth and thin and vary in length from 2¾ to about 3 inches and in width from 2 to 2½ inches; the flattened slender leaf stems are from 1¼ to 2½ inches long. The flowers have not been collected. The longish, ovate, sharp-pointed

FIGURE 19.—Foliage, twigs, and fruit of *Populus texana*. ×⅜.

seed capsules are borne on a slender, smooth stem about 2½ or 3 inches long and are deeply pitted and thin walled. They divide into three sections.

The wood has not been studied; it is probably similar to that of *P. sargentii* and *P. wislizeni.*

### OCCURRENCE AND HABITS

*P. texana* (fig. 20) grows along the moist sandy and gravelly borders of streams in canyons, where it forms narrow strips and

FIGURE 20.—Geographic distribution of cottonwood (*Populus texana*).

scattered small areas of pure growth. It is intolerant of shade in all stages of growth. In northwestern Texas it is practically the only cottonwood to be seen.

### LONGEVITY

Nothing is known now of the age limits of this cottonwood, which is apparently short-lived and of rather rapid growth in early life.

### POPULUS WISLIZENI (S. WATS.) SARG.[28]

#### COMMON NAME AND EARLY HISTORY

*P. wislizeni* in some of the books is designated as "Wislizenus' cottonwood." Wislizenus discovered it in July 1846, along the Rio

FIGURE 21.—Foliage, fruit, and flowers of *Populus wislizeni: A*, fruiting spray; *B*, staminate catkins. ×⅔.

Grande in northern Mexico. In 1854 and 1859 Torrey (*95, p. 172; 97, p. 204*) refers to this cottonwood under the name *Populus moni-*

[28] The Check List form (*90, p. 67*) of this name, possibly through a typographical error, is *Populus wislizenii*. Sereno Watson's original spelling (*100, p. 136*) is *P. fremonti wislizeni* and Sargent (*76, v. 14, p. 71*), in raising the variety to specific rank, follows the original orthography.—W. A. D.

*lifera* Ait. (*3, v. 3*). In 1878 Sereno Watson (*100*) distinguished the tree as "*P. Fremonti* var. (?) *Wislizeni.*" There long was question, however, as to its varietal relationship to *P. fremontii* S. Wats., a question which was not satisfactorily answered until 1902, when Sargent (*76, v. 14*) published the combination *P. wislizeni* (S. Wats.) Sarg., based on *P. Fremontii* var. (?) *Wislizeni* S. Wats.

### DISTINGUISHING CHARACTERISTICS

*P. wislizeni* attains a height ranging from 40 to sometimes nearly 100 feet and a diameter from about 2 to 4 or more feet. The crown

FIGURE 22.—Geographic distribution of cottonwood (*Populus wislizeni*).

is broad and rather flat in old trees and is composed of large wide-spreading branches. The large smooth twigs, rough with old leaf scars, are of pale orange-brown color and the winter buds are rather sharp pointed and shiny. The thick, firm trunk is light grayish brown and is deeply and distinctly cut into wide flattish ridges. The main ridges are laterally connected by smaller ones. Mature leaves (fig. 21) are thick and leathery in texture, smooth, yellowish green

and shiny on the upper surface, paler beneath, and from 2 to 2½ inches long and from 2¾ to about 3 inches wide. They are borne on rather slender, smooth, flattened leaf stems. The leaves of vigorous shoots are very much larger. In the fall the leaves become a bright lemon-yellow. The seed capsules, about one quarter of an inch long, are borne loosely on smooth stems from 3½ to 5 inches long and on pedicels from one half to three fourths of an inch long. The heartwood is pale yellowish brown, and the thin layer of sapwood is whitish. In general the wood is soft, brittle, and light in weight when seasoned. In drying it warps and checks badly. Locally it is often used for fuel, for temporary fence posts, and for timbering the roofs of adobe houses.

#### OCCURRENCE AND HABITS

This cottonwood (fig. 22) grows extensively in the sandy soils of broad river bottoms and along the borders of streams, usually in pure stands of considerable extent in the Rio Grande Valley where it is common. During the first 20 or 30 years it grows rapidly in an evenly moist situation and very slowly in situations that are intermittently dry and moist. It is widely planted for shade in western Texas and in New Mexico. Cuttings are used in erosion-control operations.

#### LONGEVITY

This tree is relatively short-lived and, according to present observation, attains maximum growth in about 50 years and in some instances reaches an age of 80 or 100 years.

### SOUTHERN COTTONWOOD (POPULUS DELTOIDES VIRGINIANA (FOUG.) SUDW.[29]

#### COMMON NAME AND EARLY HISTORY

This cottonwood is an inhabitant mainly of the eastern part of the United States and adjacent sections of eastern Canada, but it extends also into the Dakotas and west-central Texas. It is not strictly a Rocky Mountain tree, but because of its occurrence in the Dakotas, where a number of Rocky Mountain species are found, it is deemed advisable to include it in the Rocky Mountain tree flora.

Forty years or more ago this was one of 3 or 4 cottonwoods ranging throughout the region east of the Rockies, and all were more or less confused under the name *P. monilifera* Ait. As recently

[29] In the author's manuscript, as in the Check List (*90*), the authorities are given as "Castigl. (Sudw.)", but this combination is in error in giving the parenthesized authority as Castiglioni. Castiglioni himself (*21*) attributes the authorship of the name *Populus virginiana* (whereon the combination *P. deltoides virginiana* is based) to Fougeroux (*31*). In this connection it will be noticed that Tidestrom (*91, p. 16*), in publishing the combination *Aigeiros virginiana* (Foug.) Tid. for this same cottonwood, also attributes the specific name to Fougeroux. The distinctive nomenclatural history of this cottonwood is indicated in the following chronological statement: *Populus virginiana* Foug., Mém. Agr. Paris 1786: 87. 1787; *Populus nigra β virginiana* Castigl., Viag. Negli Stati Uniti 2: 334. 1790; *Populus deltoides virginiana* Sudw., Check List of the Forest Trees of the United States, Their Names and Ranges: 65, 1927.—W. A. D.

as 1905 these cottonwoods were assembled under the oldest name, *P. deltoides* Marsh. (some authors preferring *deltoidea*), with one varietal or specific form (*P. deltoides* var. *occidentalis* Rydb., or *P. occidentalis* (Rydb.) Britt.) inhabiting the western part of this extensive range. The different cottonwoods so long confused are very difficult to distinguish, so closely do they resemble each other in the general appearance of their foliage. It is only by an extremely careful study of their flowers, fruit, and adult leaves that a satisfactory definition of the different forms can be worked out.

What is here treated as *P. deltoides virginiana* was described by Duhamel du Monceau (*28, v. 2, pp. 178–180*) under the vernacular name *peuplier noir de Virginie*. He wrote of it as having been already successfully introduced into cultivation in France. This form appears to be the one first introduced into English gardens, probably at a much earlier date than available records now show. According to Elwes and Henry (*30, p 1808*) the only specimens in Great Britain were a tree in Oxfordshire, England, which in 1910 was 91 feet high and 35 inches in diameter, and another in Glamorganshire, Wales, about 80 feet high and 52 inches in diameter.

### DISTINGUISHING CHARACTERISTICS

Within its more eastern range this is one of the largest cottonwoods, but western representatives are smaller. The western tree ranges in height from 75 to (occasionally) 100 feet and in diameter from about 30 inches to 4 or 5 feet, or in a few individuals to 7 or 8 feet. In more or less dense stands the trunk is clear of branches for 30 to 50 feet or more, and the crown, composed of a few large spreading branches, is broad and open. Trees grown in the open with plenty of sunlight have relatively short, clear trunks, the massive branches occurring at 15 or 20 feet from the ground and producing a very broad crown, sometimes 80 or 90 feet wide. In young trees only the lower-crown branches are strongly spreading, while the upper-crown branches are upright, forming a broad pyramidal crown. The trunk bark of large trees is from 1½ to 2 inches thick (much thinner on young trees), dull gray, and sharply and deeply cut into rather wide furrows and ridges. Bark of very young trees and of branches of old trees is smooth and pale yellow with a slight tinge of green. The thickish twigs are round, but during their second season, particularly on young trees, they are marked by three rather conspicuous wing angles, one running downward from each of the two sides and the base of the three-parted old leaf scars. The resin-covered terminal buds, of a dark chestnut color, are shiny and pointed, and about one half inch long; the lateral buds are much smaller and are flattened. Mature leaves (fig. 23), which are from 3 to 4 inches long, are thickish and leathery. The upper side is smooth, yellowish green, and shiny; the under side is pale; and the midrib is yellow. The slender leaf stems, which range in length from 2 to 3 inches, are flattened laterally and are yellow or often reddish at the lower end. The clusters of seed capsules are from 7 to about 11 inches long; the capsules, somewhat elliptical in outline and pointed, are about one third of an inch long and are borne on pedicels about one fourth inch in length.

The wood is rather soft and narrow-ringed. When thoroughly seasoned it weighs approximately 24 pounds to the cubic foot. The

FIGURE 23.—Leafy and fruiting sprays of *Populus deltoides virginiana.* ×⅝.

thick layer of sapwood is almost white, and the color of the heartwood varies greatly in different trees, ranging from light to dark

brown. Twenty-five or thirty years ago the large logs were rather extensively cut into inch boards and dimension lumber to furnish cheap building material. The wood is now used for paper pulp, slack cooperage, packing boxes, and, in the western part of the tree's range, for poles, temporary fence posts, and fuel.

### OCCURRENCE AND HABITS

This cottonwood (fig. 24) grows along streams and in river bottoms in moist, rich, alluvial soils, often in situations inundated for a part of the year. It occurs in scattered groups and thin lines

FIGURE 24.—Geographic distribution of southern cottonwood (*Populus deltoides virginiana*).

bordering slow-flowing streams and inland lakes and ponds, but in broad river bottoms it often forms open or rather dense pure stands. It is intolerant of shade during all stages of its growth.

### LONGEVITY

This is a relatively short-lived tree. It attains its maximum height and diameter growth in from 50 to 60 years, growing rapidly (in rich well-drained soils) during the first 35 or 40 years of its life. After reaching maturity it grows very slowly, but it may remain in sound and vigorous condition up to 100 or 125 years, or possibly more.

## MACDOUGAL COTTONWOOD (POPULUS MACDOUGALII ROSE)

### COMMON NAME AND EARLY HISTORY

MacDougal cottonwood was first discovered by D. T. MacDougal at Colonia Lerdo,[30] Sonora, Mexico, in February 1904. Specimens and excellent photographs of the tree were at the time obtained by

FIGURE 25.—Foliage and buds of *Populus macdougalii: A*, Staminate catkin buds and adult form of large, vigorously grown leaf; *B*, form of foliage on large trees (upper crown). ×½.

MacDougal, who apparently suspected it to be an undescribed species, for he referred this material to Rose, who considered it new. However, the latter did not publish an account of it until September

[30] In a letter from Dr. MacDougal, dated Jan. 3, 1925, he writes as follows concerning the location of this Mexican town: "Colonia Lerdo was at the extreme head of tidewater on the Colorado River about 80 miles south of the point at which the international boundary strikes the river from the Arizona side. * * * I consider all of the *Populus* in the delta to be of this one kind. Specimens were taken at this place in 1904 and I believe that other material was taken near Yuma in 1905."

3, 1913 (*66*), just previous to which S. B. Parish supplied the following further information about the tree:

I am sending you under another cover specimens of a *Populus* which does not well agree with any species of which I have a description. It belongs in the delta lands of the Colorado River, at least to Yuma, where it is abundant in the bottom lands on both sides of the river. It also comes into the Salton Sink, along the Alamo and New Rivers. In the settled part of the Sink it is very generally cultivated but is not indigenous. The Indio and Mecca specimens are from cultivated trees.

FIGURE 26.—Foliage and seed capsules of *Populus macdougalii*. × ⅝. *A*, A seed, natural size.

DISTINGUISHING CHARACTERISTICS

*P. macdougalii* is usually from 30 to 60 feet in height and from 12 to 18 inches in diameter; exceptionally large trees are 80 or 90 feet high and 25 or 30 inches through. A striking characteristic of this cottonwood when grown in a dense stand is its large branches, sharply ascending from a short clear trunk. The crowns

of trees grown in the open are made up of 6 to 10 sharply ascending large branches, the length of even the lowest of which often nearly equals that of the central upper branches. Altogether these produce a flat-topped crown broadest near the top. Young trees in the open have a rather narrow columnar-shaped crown until they become 5 or 6 inches in diameter, when the lower branches develop rapidly until they nearly equal or sometimes exceed the height of the upper branches. The trunk and large branches are clothed with slender twigs. Bark of large trunks is grayish and furrowed and ridged only near the ground; higher up and on the large branches it is smooth and unbroken and is of a light ash-gray color which often

FIGURE 27.—Geographic distribution of MacDougal cottonwood (*Populus macdougalii*) in the United States.

appears nearly white. The round twigs of the first season's growth are light gray and usually more or less hairy; during the second season they are commonly smooth, but occasionally are somewhat hairy. Mature leaves of adult trees (fig. 25, *A*), which are from 1½ to 3 inches long and of the same or of greater width, are smooth and blue-green; the slender, flattened leaf stems are smooth, or sometimes scantily hairy, and are from 1½ to 2¼ inches long. Leaves of juvenile trees are commonly wedge-shaped at the base, especially those of seedlings. The clusters of seed capsules are smooth and are from 1¾ to 2 inches long; seed capsules, thickly set on the stems and

borne on pedicels about one fifth of an inch long, are ovate and pointed, slightly pitted, and when ripe split into three parts (fig. 26). Nothing is known now regarding the characteristics of the wood, which is much used locally for fuel, corral poles, and temporary fence posts.

#### OCCURRENCE AND HABITS

*P. macdougalii* (fig. 27) inhabits moist, rich alluvial river bottoms, often forming dense pure stands of considerable extent, particularly on both sides of the Colorado River in the vicinity of Yuma. Because of constant changes in the stream bed, numbers of trees growing along the river in the unstable silt and sand are frequently undermined by the water and washed away. The seedlings are reproduced in dense thickets along the borders of the river on moist silt and sand. The tree is intolerant of shade at all ages. It grows naturally in a region of high temperatures and low atmospheric humidity.

*P. macdougalii* is often planted along streets in towns near and within its natural range and is the only tree planted at many stations along the line of the Southern Pacific Railroad in and near the Salton Sink.

#### LONGEVITY

Nothing is known definitely regarding the age limits of this tree. It appears to grow rapidly during the early years of its life, but like related species it is probably short-lived, not attaining an age greater than 70 or possibily 100 years.

## GENERIC CHARACTERISTICS OF THE WILLOWS

The deciduous leaves, variable in form, of most of the willows are long and narrowly pointed, smooth, or coated with fine silky hairs on the under surfaces. The margins may be entire (uncut) or variously toothed. The leaves are characterized by a pair of earlike minute or large bracts, or stipules, at the base of the leaf stem. The bracts are larger and more conspicuous on vigorous new shoots, on which they may remain until they fall with the leaves; on other twigs they are present only during the early growth of the leaves. The foliage may be shed in the autumn without much change of color, or it may turn lemon yellow before falling. Leaf scars are marked by three minute dots of fibro-vascular bundles. Sterile flowers are mostly in pairs, with distinct or united stamens. Stigmas are short. Catkins appear with the leaves or a little before. Buds are covered with a single scale, in contrast with the several scales of poplar buds.

The minute and sometimes slightly fragrant flowers of the willows appear before the leaves expand or at the same time. They are arranged more or less thickly on a central drooping or erect stem (rachis) and altogether form a cylindrical or elliptical-shaped cluster ranging in length, according to the species, from one half inch to 2 or 3 inches and in diameter from about one fourth to three

fourths of an inch. As a rule, the staminate aments are bright yellow, but sometimes they are a dull yellow, yellowish green, or pale rose. The clusters of pistillate flowers are much less conspicuous, usually being greenish. The little aments spring from lateral or side buds borne on twigs of the previous year's growth. In some cases these bear only the flowers, but in others a few small leaves occur just beneath the flowers. Each flower has a minute, usually entire-margined scale or bract at its base. The twigs of willows are for the most part tough and withy, but usually they are readily broken off where they join the branch.

Annual stump sprouts of willows are exceedingly strong and withy, but twigs from the crown are often very brittle, especially where they are joined to a branch. Many of the willows produce several trunks from a single greatly extended rootstock, but some species regularly produce single isolated trunks. Such species are readily admitted to be trees; those forming clusters of large trunks sometimes have been denied this rank, even though the trunks were otherwise treelike. For all practical purposes, however, they are trees and should be so considered.

The willows have remarkable vitality and grow persistently from cut stumps and easily from cuttings or pieces of branches or roots. This vitality and readiness of growth have been exploited in some foreign willows, which for centuries have been pollarded to cause them to produce long slender rods used in the manufacture of crates and coarse baskets, for fuel, and for other purposes.

The pistillate trees of practically all the arborescent willows produce an abundance of seed which is widely distributed by wind and water. The seed germinates and seedlings develop quickly in moist sand, muck, or other moist soils, and dense thickets are often produced.

As a group, the willows are intolerant of dense shade, their best development being attained in full sunlight. They are usually but not universally swamp or moist-ground plants, finding their habitat from sea level to an elevation of 10,000 or more feet.

Some of the tree willows produce moderately large, clear trunks which would yield lumber, but as a rule their boles are poorly formed for sawing. Except in generally forestless regions, where willows and their associates, the cottonwoods, become useful because no other trees are available, these trees have little to commend them in comparison with many other trees of demonstrated value. Willow wood is soft, light, usually brittle, but firm; commonly pale brown tinged with red. The wood of some species is very durable when exposed to water or earth. Willow wood has various economic uses, especially for baseball and cricket bats and for gunpowder and charcoal, but the greatest commercial use of willows appears to be that of shoots in the manufacture of baskets and furniture.

Willows are distinctly important to the forester because of their effectiveness in binding shifting sands and holding the banks of streams in soft bottoms where extensive ruin of agricultural lands may result from the erosion of unprotected banks. Willow cuttings are used in controlling gullies.

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Tree willows attain maturity in 50 to 150 years; after maturity the trunks usually become hollow and may gradually show other signs of decay. They are then easily broken by storms. The vitality of the tree, however, allows it to remain alive for centuries, new stem or root sprouts repairing or replacing broken trunks.

Over 100 species of willow occur on this continent, and of these about 35, perhaps more, attain tree size.

The willows are of very ancient origin. Their geological history has been described by Berry (*14*) and others (*49; 50; 51; 52; 73; 76, v. 9; 105*). They make their appearance in the geological record during the Cretaceous period, when at least a score of species were in existence in North America, Europe, and probably in Asia. The genus undoubtedly originated in the holarctic region. Upwards of 100 species are known from Tertiary deposits, at which time the willows appear to have been widespread throughout the Northern Hemisphere, penetrating as far north as Greenland. During the glacial period the Arctic willows of the tundras extend their ranges southward, and their remains are found as far south as New York in the United States and Switzerland and Galicia in Europe. Many of the existing species were already present in the Pleistocene.

With few exceptions the various species of willow are difficult to identify, especially before they become trees. As a class, however, nearly everyone will recognize them as willows. But many even of the most important ones can be distinguished only by a careful study of their mature leaves, bark, twigs, and habits of growth. Individual trees are likely to be found that can only be identified through a close examination of the minute characters of the male and female flowers and the tiny seed capsules.

## KEY TO THE WILLOWS DESCRIBED IN THIS BULLETIN[31]

Stamens 2. (Section *Diandrae*):

Stipe (i.e., stalklike base) of ovary and capsule longer than the subtending bractlet. Bractlets[32] persistent; filaments free and glabrous; capsules beaked.

Ovaries and capsules glabrous; leaves usually broadest towards the base; bractlets dark brown, hairy at base only. Twigs sometimes yellowish but mostly dark brown; leaves mostly of a lanceolate type, distinctly petioled, crenately serrulate, pale below, thin but firm ..... *Salix mackenzieana*

Ovaries and capsules finely villous or pubescent with silky white hairs; leaves mostly broadest towards the apex; bractlets usually pale but sometimes tawny and usually rose colored at apex, villous-hairy throughout, of a narrow (lance-oblong) type. Leaves firm, pubescent or glabrate, elliptic-lanceolate to obovate, mostly acute, sometimes entire but usually entire below and irregularly and remotely toothed from about the middle upwards; pistillate aments slender, lax ..... *S. bebbiana*

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[31] Key prepared by W. A. Dayton, based largely on the treatment of Ball *ex* Abrams (*2*), Wooton and Standley (*104*), Standley (*83*), Rydberg (*71*), and Sargent (*79*). The nomenclature, however, is of course that of Mr. Sudworth.

[32] I.e., the small bracts, called "scales" by many authors, in the axils of one of which each of the amentaceous flowers of *Salicaceae* is borne.

Stipe of ovary and capsule conspicuously shorter than the subtending bractlet.

Filaments united below the middle, glabrous; bractlets persistent, dark tawny, rounded, villous with long crisp white hairs, blunt or truncate at tip. Leaves typically oblanceolate, sometimes lanceolate or narrowly elliptic, 6–15 cm long, mostly acute, strongly reticulate, minutely denticulate or entire, short-villous when young, in age glabrous and shining above, and glaucous and usually more or less villous beneath; aments appearing before the leaves, sessile or nearly so, dense, the staminate about 12 mm thick, nearly twice as thick as the pistillate aments; ovaries and capsules glabrous; style evident (0.5 to 1 mm long); stigmas short ..... *S. lasiolepis*

Filaments free.

Bractlets deciduous, pale yellowish; filaments more or less hairy.

Leaves very small (1 to 3 cm long), usually not over three fourths inch (18 mm) long, linear-lanceolate, almost yewlike, entire or nearly so, finely pubescent. Southwestern species; season's twigs woolly; aments very short, the staminate 5–13 mm long and the pistillate in fruit, 12–20 mm long; bractlets woolly on outer surface; filaments hairy below the middle; anthers globose or nearly so; ovaries and capsules pubescent ..... *S. taxifolia*

Leaves larger (more than 3 cm long), not at all yewlike; aments much larger (1–3 cm long). Bractlets villous; filaments slightly hairy at the base; stigmas sessile (no style).

Leaves sericeous-canescent below when mature, 5–8 cm long, mostly not over 8 mm wide, sessile or very short-petioled, linear to linear-oblong, yellowish green, those of the flowering twigs entire or nearly so; stipules minute or wanting; staminate flowers with 2 glands; capsules sessile or nearly so, usually glabrous ..... *S. exigua*

Leaves glabrous or nearly so below and bright green and glabrate above when mature, linear-lanceolate, 5–15 cm long, those of the flowering twigs denticulate; stipules ovate-lanceolate, deciduous, about 6 cm long; capsules 7 mm long, usually somewhat pubescent when young but glabrate in age ..... *S. longifolia*[33] (=*S. interior* and "*S. fluviatilis*" of some authors)

Bractlets persistent, dark fuscous to blackish, hairy; filaments glabrous. Leaves mostly of an obovate type but varying to oblanceolate or oblong-elliptic, usually cuneate at the base and obtuse or acutish at apex, 3–12 cm long, usually entire but varying to crenulate-serrulate, thickish, dull green or slightly shiny and glabrate above, variable beneath (silvery, rusty pubescent, glabrous, or glaucous-reticulate); aments dense, stout; styles very short (not over 0.3 mm long); stigmas long and slender; capsules reddish brown, pubescent, 8 mm long. The commonest willow of the Pacific region, often invading burns; bark reddish brown with (like the young leaves) a disagreeable odor ..... *S. scouleriana*[34]

Stamens more than 2 (usually about 5). Bractlets deciduous, pale yellowish; filaments free, hairy at the base. (Section *Pleiandrae.*)

Leaves green on both sides. Twigs brittle (i.e., easily separable, as if articulated); petioles without glands at junction of blade.

Ovaries and capsules glabrous; twigs (often reddish or purplish) brown. Leaves lanceolate, long-acuminate, short-petioled; aments long and lax; bractlets pale hairy within; stigmas nearly sessile; capsule stipe or pedicel much shorter than the body of the capsule. *S. nigra*

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[33] This name is a homonym and untenable under either botanical code (p. 74). To this species belong the two varieties mentioned by Mr. Sudworth, *S. longifolia angustissima* (with sericeous ovaries and absence of glands in the male flowers) and *S. longifolia pedunculata* (with longstalked fruit, glabrous ovaries, and narrower, linear leaves).

[34] Mr. Sudworth follows Sargent (79) here in separating off a Rocky Mountain-Sierra variety, *S. scouleriana flavescens*, having yellowish-green twigs and yellowish-green, obovate-rounded leaves.

Ovaries and capsules woolly-hairy; twigs yellowish, slender. Leaves lanceolate or elliptic-lanceolate; no stipules; bractlets woolly; capsules 3–4 mm long, the stipe or pedicel nearly equal to the capsule body; stigmas sessile ..... *S. gooddingii*

Leaves not of the same hue on both faces, paler and usually more or less bluish (glaucescent) beneath, at least when mature. Ovaries and capsules glabrous.

Petioles glandular; twigs "brittle", i. e., easily separable, brown, and shining. Leaves lanceolate to ovate-lanceolate, acuminate, about 8–12 cm long, dark green and shining above; aments elliptic-oblong; bractlets (especially of staminate aments) toothed (in typical forms to the base) ..... *S. lasiandra*[35]

Petioles without glands.

Bractlets untoothed (entire). Twigs "brittle", i.e., easily separable.[36]

Twigs dark orange to red brown, shining, occasionally somewhat hairy (pilose); stipe or pedicel of capsule about two thirds as long as bractlet. Leaves acuminate, thin, broadly lanceolate, on slender petioles (leafstalks) 6–15 mm long; stamens about 5–9; style evident though short; bractlets sparsely villous-hairy on the outside, densely villous inside. *S. amygdaloides* (in typical form)

Twigs bright yellow or yellowish brown, hairless (glabrous); stipe or pedicel of capsule about as long as the bractlet. Leaves stomata-bearing on the upper surface, short-acuminate, usually broadest at or above the middle; aments short, thick, and dense; stamens 5 or 6; bractlets villous-hairy on the back. A southwestern form (western Texas-New Mexico-northern Mexico).

*S. amygdaloides wrightii* (=*S. wrightii*)

Bractlets rather irregularly toothed, villous-hairy at least on the outside. Twigs rigid—not easily separable.

Twigs glabrous, i.e., hairless (yellowish, brownish, reddish, or purplish);[37] leaves silvery white below, narrow, finely toothed, more or less persistent through the winter; stamens usually three; capsules 4–5 mm long, with a cuplike glandular disk, their stipes or pedicels not more than one half as long as the capsule body; stigmas nearly sessile. Southwestern tree ..... *S. bonplandiana toumeyi* (=*S. toumeyi*)

Twigs pubescent when young, yellowish or reddish brown; leaves dark green and glossy above, glaucous (bluish) beneath and often with rather long yellowish hairs beneath, at least when young, 7–15 cm long, lanceolate or lance-oblong (at least when mature), long-acuminate; aments of a narrow type (linear) 5–10 cm long; stamens 4–6; capsules about 6 mm long, without a cuplike disk at the base, their stipes or pedicels about two thirds as long as the capsule body; stigmas minute. California-Nevada-western Arizona species ..... *S. laevigata*

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[35] Mr. Sudworth recognizes two varieties of *S. lasiandra*, viz, *S. lasiandra caudata* and *S. lasiandra lancifolia*, which may be keyed as follows:

Leaves green on both faces though darker above; twigs not hairy, or at least not conspicuously so. Twigs yellowish; leaves rather thick and leathery, about 2–4 inches (5–10 cm) long, wedgelike (cuneate) at base, the tips often falciform caudate (i.e., with a curving, taillike acumination); staminate aments thick and dense; buds hairy; bractlets toothed toward apex only; shrub or small tree ..... *S. lasiandra caudata* (=*S. caudata*, *S. pentandra caudata*, *S. lasiandra fendlerian* and "*S. fendleriana*," at least in part)

Leaves grayish or rusty pubescent on the lower surface; twigs grayish or rusty pubescent. A Pacific, especially North Pacific, (hardly Rocky Monutain) form. *S. lasiandra lancifolia*

[36] Authorities are not agreed on the extent of this character in typical *S. amygdaloides;* field observations on this point appear to be needed.

[37] Authorities seem not to be agreed as to twig color in *S. bonplandiana toumeyi;* field observations are evidently needed.

## BLACK WILLOW (SALIX NIGRA MARSH.)

### COMMON NAME AND EARLY HISTORY

*S. nigra*, perhaps the best known of our tree willows, is very generally known as black willow, a common name doubtless sug-

FIGURE 28.—Flowering and fruiting sprays of *Salix nigra*. ×1.

gested by the blackish trunk bark. In some parts of its range this willow is occasionally called swamp willow, because it grows in wet bottom lands.

The black willow first became known to science in 1785. Humphrey Marshall, a resident of Chester County, Pa., described it at that time and named it *Salix nigra* in his now famous work on American trees and shrubs (*57*), a publication which has the distinction of being the first book on plants written by an American. While the history of this willow is generally free from confusion insofar as American authors are concerned, European writers applied 6 or 7 other specific names to it from 1788 to 1829, and 9 or 10 subspecific, varietal, and subvarietal forms of the tree were described and named during the succeeding 30 years. These segregated forms are, however, properly held to be phases only of one variable species of an exceedingly wide range.[38]

Schneider (*81*) in 1918 renamed a variety of the black willow *S. nigra* Marsh., var. *lindheimerii* Schn., which Andersson described in 1868 (*8, p. 199*) as *S. humboldtiana* γ *oxyphylla* (H.B.K.) Anderss., a varietal name that under present rules of nomenclature cannot be used. Schneider gives its range as—

> eastern and southern Texas (perhaps also in southern Oklahoma), from about 34° N. latitude and between 100° and 95° W. longitude southward into Mexico to southeastern Coahuila, Nuevo Leon, and to Tamaulipas (and probably also Hidalgo).

Since Andersson originally described this willow it has been variously held to be either a form of *S. humboldtiana* or of *S. nigra*. Schneider (*81*) further states that this seems to be the most southern form of *S. nigra*, from typical forms of which it differs in usually having narrower leaves (at least more attenuated at the base) with comparatively much longer leafstalks. The young twigs and leafstalks are hairless or rapidly become so, whereas in typical *S. nigra* they are for a considerable time distinctly downy or hairy. Moreover, the stipules of this variety are described as having minute yellowish glands on the inner surface, which are absent in the stipules of typical *S. nigra*. The seed capsules also are slightly larger (about ¼ inch long) than those in typical forms of the black willow (about ⅛ inch long).

Bebb (*12, pt. 3*) has described a hybrid of which this willow was one of the parents.

*S. nigra altissima* Sarg., a variety differentiated in 1913 (*77, v. 2, p. 216*), occurs abundantly in Louisiana, southern Arkansas, and eastern Texas. It is distinguished from the typical form of *S. nigra* by its greater height growth (it occasionally attains more than 120 feet), more pubescent twigs, more pubescent and narrower-based blades, more pubescent and larger leafstalks (petioles), and by its habit of flowering 2 to 3 weeks later than ordinary black willows.

### DISTINGUISHING CHARACTERISTICS

Black willow is the largest and most widely known of the native willow trees, but it is much less abundantly represented in western United States than in the Eastern States. It is more distinctly a tree throughout its range than almost any other arborescent willow

[38] Elwes and Henry (*30*) do not mention the black willow as a cultivated tree in English gardens, and probably it is not represented there at the present time. However, Loudon (*56, v. 3, p. 1529*) says that *Salix nigra* was introduced into cultivation in England in 1811, adding that (in 1838) "There are plants in the Hackney and Goldworth arboretums, and at Woburn Abbey."

and for this reason is probably the one most commonly recognized. Occasionally it forms a single trunk, but usually several trunks grow from the same root. Very commonly it is from 25 to 50 feet in height and from 10 to 20 inches in diameter. Trees from 60 to 80 or more feet in height and from 2 to 3 feet in diameter are of rather rare occurrence. The trunks are nearly always somewhat bowed and leaning. In scattered, open stands the trunks are clear of branches for one third or one half of their length and in close stands for two thirds of their length. The branches trend upward some-

FIGURE 29.—Geographic distribution of black willow: *A–A, Salix nigra falcata; B–B, S. nigra altissima; C–C, S. nigra lindheimerii.*

what, forming a wide, round-topped, open crown. Rough, furrowed, blackish-brown bark with wide, thick-scaled ridges and narrower connecting ridges is a marked characteristic of this tree, as is also the brittleness of the slender, drooping branchlets at their bases. The pale yellow-green leaves range in size and shape from fairly straight or slightly curved to strongly curved or scythe-shaped (fig. 28) and are from 2½ to 5 or 6 inches long. They are smooth and somewhat shiny on the upper surface and smooth beneath, where

the veins are sometimes minutely hairy. The margins of the leaves are finely toothed.

Heartwood of the black willow is pale reddish brown, soft but firm, and rather fine-grained. A cubic foot of thoroughly seasoned wood weighs about 26 to 28 pounds (*48, p. 91*).

For a long time the wood of this species was used locally, chiefly for fuel and charcoal and occasionally for ball bats. At present it is also used extensively for packing cases, berry boxes, artificial limbs, woodenware, excelsior, boat scoops, and bucket handles, and as a substitute for yellow poplar for the backing and other unseen parts of furniture.

#### OCCURRENCE AND HABITS

*S. nigra* (fig. 29) grows naturally on the borders of streams and on low flats, in humus-covered wet or moist gravelly and sandy soils and is found commonly along the lower levels of watercourses in New Mexico. It forms strips and occasionally small patches of pure growth and is in some places mixed with other willows, cottonwoods, and alder. The largest trees are found in the valleys of the Mississippi, Ohio, Wabash, and White Rivers, in some parts of which black willow forms the principal tree growth over considerable areas. The regions of its best development are marked by moderate temperatures; this does not, however, properly account for the comparative rarity of this willow in the Pacific region. Black willow is decidedly intolerant of shade throughout life. It produces an abundance of seed, which is widely distributed by the wind and by streams. Reproduction takes place most frequently and abundantly on wet humus and sand.

#### LONGEVITY

Not much is known of the extreme age limits attained by the black willow. It is, however, essentially a short-lived tree, although the rootstock may continue to produce new sprouts for a great many years. Trees from 10 to 18 inches in diameter are from 35 to 60 years old. Occasional large trees from 2 to 3½ feet in diameter are estimated to be from 125 to 150 years old.

### DUDLEY WILLOW (SALIX GOODDINGII BALL)[39]

#### COMMON NAME AND EARLY HISTORY

*S. gooddingii* is a little-known willow which for a number of years was not distinguished from southwestern forms of the black willow. Commonly it is known only as willow, although its two book names are Dudley willow and Goodding willow.

The botanical history of this willow dates from 1904, when it was technically described (*1*) from southern California specimens as a variety of the black willow (*S. nigra* var. *vallicola* Dudl.); in 1908 it was termed a species, *S. vallicola* (Dudl.) Britt. (*19*). The former

[39] The Check List (*90*) uses the spelling *gooddingii*, but Ball's original description (*9, p. 376*) used the form *gooddingi*.—W. A. D.

FIGURE 30.—*Salix gooddingii: A*, Fruiting spray; *B*, staminate spray. ×⅜.

name is the oldest one applied to this tree, but owing to a rule of nomenclature it cannot be maintained. Accordingly, Ball (*9, p. 376*) renamed the species *S. gooddingii.* The oldest specimen now preserved of *S. gooddingii* was collected in 1845 by Frémont himself in his expedition to California, but definite record was not made of the locality, which was either in Utah or Arizona (*10, p. 231*).

FIGURE 31.—Geographic distribution of Dudley willow (*Salix gooddingii*).

Other early records show that it was found on the Piute River in 1861, and in Lake County, Calif., in 1863.

### DISTINGUISHING CHARACTERISTICS

*S. gooddingii*, although sometimes shrubby, is ordinarily a tree from 20 to 45 feet in height and from 10 to 30 inches in diameter. Widely scattered as the tree usually grows, it produces a broad rounded crown and a very short clear trunk. Occasionally in crowded stands it has a tall slender stem and a narrow columnar crown of short branches. Often the crown is composed of several large trunklike stems rising from near the ground. The thick, firm, gray or blackish trunk bark is cut with deep furrows and narrow ridges. The slender, easily detached twigs are straight, yellowish, more or

less shining, and often slightly hairy. Twigs of a season's growth are usually densely woolly.

Mature leaves are dull green and smooth and are from 1½ to about 3 inches in length and from about one fourth to one half of an inch in width (fig. 30). They vary in form from narrowly to broadly lance-shaped and are commonly slightly curved above the middle; the apex is gradually or sometimes abruptly narrowed to a sharp point. The base of the leaves is wedge-shaped and attached to the twigs by a stem about one fourth of an inch long or less. At first the leaf stems are woolly, but later they become smooth. Margins of the leaves are finely cut with shallow glandular teeth. The beaked, red-brown seed capsules, borne on threadlike pedicels, are at first woolly but usually become smooth at maturity.

#### OCCURRENCE AND HABITS

As now known, *S. gooddingii* (fig. 31) grows naturally in moist ground along watercourses and about springs from western Texas (El Paso and Jeff Davis Counties) through southern New Mexico to central and southern Arizona and southeastern Nevada (Lincoln County). Thence it extends into northern Baja California and northward in the interior of California to the northern part of the State (Shasta and Tehama Counties). It also occurs in northern Mexico.

#### LONGEVITY

Nothing is known now regarding the age attained by *S. gooddingii*. Apparently, however, it is likely to be similar in this respect to *S. nigra*, which attains maturity in from 50 to 75 years, although trees may remain in vigorous condition much longer.

### PEACHLEAF WILLOW (SALIX AMYGDALOIDES ANDERSS.)

#### COMMON NAME AND EARLY HISTORY

*S. amygdaloides* is rarely if ever recognized by laymen as distinct from other tree willows, and for this reason it is usually called simply willow or common willow throughout its Rocky Mountain range. The most common names of this willow are peach (leaf) willow and almond (leaf) willow, both of which names obviously reflect the resemblance of the leaves of this American willow to the foliage of the cultivated peach and almond (*Amygdalus* spp.). These resemblances, and the relationship to the European species *S. amygdalina* L., doubtless suggested the technical name *S. amygdaloides*.

The peachleaf willow became known to science in 1858, when the Swedish botanist Andersson described it as *S. amygdaloides* from specimens which appear to have been collected in Missouri (*5*). Ten years later, apparently believing it to be a form of the black willow (*S. nigra* Marsh.) he named it *S. nigra* var. *β amygdaloides* (*8*). As we now know this willow, it is generally held to be distinct from the black willow.

DISTINGUISHING CHARACTERISTICS

The peachleaf willow produces one straight or leaning trunk or very rarely several clustered stems, like the black willow. Its upright branches are peculiarly straight, forming a rather compact,

FIGURE 32.—Leafy sprays of *Salix amygdaloides*. ×½.

round head. Ordinarily, the tree is from 20 to 30 feet high and from 8 to 12 inches in diameter, but occasional trees are from 40 to 50 feet in height and from 16 to 18 inches in diameter. The very pale reddish-brown trunk bark is about half an inch thick and is

rather deeply furrowed, the wide ridges being thick-scaled and connected by narrower lateral ridges. The twigs are straight, slender but rather tough, shiny, and red to orange-brown. Mature leaves (fig. 32) are thin, smooth, shiny, and light yellow-green above and pale or whitish (glaucous) on their under surfaces. The

FIGURE 33.—*Salix amygdaloides wrightii*, syn. *S. wrightii*: *A*, Staminate spray; *B*, pistillate (fruiting) spray. ×½.

borders of the leaves have minute teeth with glandlike points. The prominent midveins range in color from a conspicuous light yellow to dark yellow. The leaves vary in length from about 2¾ to 4 inches and in width from about three fourths of an inch to 1¼ inches.

Staminate and pistillate flower clusters, which are usually found at the ends of short leafy twigs, are narrowly cylindrical, more or less woolly, and from about 2 to 3 inches long. The stamens vary in number from 5 to 9 and are distinct from each other. The flask-shaped seed capsules are smooth, deep orange-yellow, and about one fourth of an inch long. They are borne on rather long pedicels.

Wood of this species is pale yellow-brown, soft, brittle, and narrow-ringed, weighing about 28 pounds to the cubic foot. So far as is known the wood has no commercial uses, but it is cut locally for fuel and fence posts. It appears that the annual shoots of this willow have been tested in basket making, for which use they would

FIGURE 34.—Geographic distribution of peachleaf willow (*Salix amygdaloides*).

seem to be adapted. They are straight, slender, and tough, resembling those of the almond willow (*S. amygdalina*) of Europe, which is one of the standard willows cultivated for basket rods.

### OCCURRENCE AND HABITS

Peachleaf willow (fig. 34) grows naturally along the borders of perpetual and intermittent streams, in moist rocky or gravelly soils, where it forms interrupted lines and small groups. Reproduction occurs rather sparingly and only along the moist open borders of streams and about springs and water holes, in sand, gravel, or silt.

### LONGEVITY

Little is known of the age attained by the peachleaf willow. It grows rapidly in height and diameter during the first 25 or 30 years. Trees from 7 to 10 inches in diameter are from 25 to 40 years old; those from 18 to 24 inches in diameter are probably from 75 to 100 years old.

In 1918 Schneider (*81, p. 14*) designated *S. amygdaloides* var. *wrightii* as a varietal form of the peachleaf willow, ranging from

western Texas to southern New Mexico and south into northern Chihuahua. This varietal name is based on *S. wrightii* Anderss. (1858) (*5*), of which *S. nigra wrightii* Anderss. (1868) is a synonym (*8*). Ball (fide Schneider) (*81, p. 14*) regards this form as a distinct species, as do also Britton and Shafer (*19, p. 185*) and Rydberg (*71, p. 191*). In Schneider's opinion, however, it is a variety only, differing from typical *S. amygdaloides* chiefly in its more distinctly yellowish branchlets and its more lanceolate and more often acute (rather than long-acuminate) leaves, all of which have numerous stomata in the upper surface, and are mostly broadest at or above the middle.

The characters indicated do not appeal to the writer as of specific weight, and, for the present at least, he is inclined to accept Schneider's view and maintain this phase of peachleaf willow as a variety, *S. amygdaloides wrightii* (Anderss.) C. Schn. (fig. 33). From its general resemblance to *S. nigra* it is sometimes called black willow, and the book name Wright('s) willow is also applied to it.

## RED WILLOW (SALIX LAEVIGATA BEBB)

### COMMON NAME AND EARLY HISTORY

*S. laevigata* is commonly known as red willow, in allusion to the dark orange or bright red-brown twigs. It is also called black willow and California black willow, probably because the trunk bark of older trees is dark or blackish brown. Other names applied are smoothleaf willow and polished willow, because of the smooth, shiny upper surface of the leaves. Occasionally it is called Bebb willow, in honor of the eminent salicologist who described it.

This willow in typical form became known to science in 1874, when it was described under its present technical name (*11*). It was long supposed to be an inhabitant only of western California, where it was discovered. The first collection of red willow seems to have been at Santa Cruz, Calif., about 1852, by Andersson. However, Bebb not only had Andersson's specimen before him when he wrote his original description of the species but also specimens from Alameda and Mendocino Counties, Calif. The earliest statement that this willow ranges outside of California appears to have been made in 1908 by Britton and Shafer (*19, p. 187*) when they defined its range as extending eastward into Nevada and Utah.

### DISTINGUISHING CHARACTERISTICS

The red willow is a straight-trunked tree ranging in height from 25 to 40 feet (occasionally 50 feet) and in diameter from 12 to 24 inches. The dark or blackish-brown trunk bark of large trees, sometimes faintly tinged with dull red, is about an inch thick and is deeply cut by furrows and ridges irregularly connected by narrow lateral ridges. Bark of young trunks and large limbs is much thinner and only shallowly furrowed. The crown, made up of rather slender, more or less spreading branches, varies from elongated in young trees to round-topped in old trees. Mature leaves, from 3 to 7 inches long and three fourths of an inch to 1½ inches wide, are smooth through-

out, shiny and dark green on the upper surface, and bluish (glaucous) on the under surface, with very finely toothed margins turned slightly under (fig. 35). The wide, grooved leaf stems are minutely hairy and up to about half an inch long, the wide yellowish midvein being conspicuous on the upper surface of the leaf and indistinctly visible on the under surface. The cylindrical staminate and pistillate flower clusters, 2 to 4 inches in length and occurring on ¼- or ½-

FIGURE 35.—Leafy sprays of *Salix laevigata*: *A*, Fruiting (pistillate) spray; *B*, staminate flowering spray. × ½.

inch stems, are borne singly at the ends of short small-leafed twigs and, as a rule, are slightly drooping. The stamens, commonly 5 or 6 in number and having separated filaments hairy at the base, are accompanied by a small, pale, minutely hairy, thin scale, delicately toothed at the apex. A similar, but narrower scale accompanies the pistillate flower. The elongated conical seed capsules, on rather long pedicels, measure scarcely one fourth of an inch. Wood of the red

willow is narrow-ringed and brittle, the thick layer of sapwood being whitish and the heartwood pale reddish brown. A cubic foot of seasoned wood weighs slightly less than 30 pounds. None but very occasional local use is made of the wood.

### OCCURRENCE AND HABITS

The red willow (fig. 36) grows only in moist sand and gravel along the borders of streams in the mountains and at lower elevations. It occurs singly or in small clumps and patches and is some-

FIGURE 36.—Geographic distribution of red willow (*Salix laevigata*).

times associated with other willows and occasionally with alders. It grows at elevations ranging from about 1,900 to 3,000 feet in its California range, but in the central and southern Rocky Mountain region at somewhat higher levels.

### LONGEVITY

The age limits of this willow have not been fully determined. It grows rapidly during the first 10 or 15 years and slowly thereafter and appears to be short-lived. Trees from 10 to 14 inches in diameter are from 28 to 40 years old.

## TOUMEY WILLOW (SALIX BONPLANDIANA TOUMEYI (BRITT.) C. SCHN.)

### COMMON NAME AND EARLY HISTORY

Toumey willow is a little-known variety to which the book name of Toumey's willow was first applied by Britton and Shafer in 1908 (*19*). Until that time this willow was confused with the Bonpland willow (*S. bonplandiana* H. B. K.), the range of which is in central and southern Mexico. Considering this variety to be specifically distinct from the Bonpland willow, Britton (*19, p. 187*) described it in 1908 as *S. toumeyi* Britt. In 1918 C. Schneider (*81, p. 20*) designated it as *S. bonplandiana* var. *toumeyi* (Britt.) C. Schn. While further investigation may possibly show it to be specifically distinct from *S. bonplandiana*, the writer believes that it should be maintained as a variety.

The discovery of *S. bonplandiana toumeyi* within the United States was on September 11, 1893, when Mearns collected a specimen of it in a canyon on the east side of the San Luis Mountains in Hidalgo County, southwestern New Mexico. The second collection within the United States was by W. M. Canby, J. W. Toumey, and C. S. Sargent who found it in February 1894 in Sabino Canyon, Santa Catalina Mountains, Pima County, Ariz., and described it as a tree 25 to 30 feet high. (*12, pt. 1, p. 364; 76, v. 9, p. 120.*)

### DISTINGUISHING CHARACTERISTICS

*S. bonplandiana toumeyi* attains a height of 20 to sometimes 50 feet and a diameter of 8 to 16 inches. It has a rather broad, rounded crown of slender branches and twigs, which trend sharply upward but are more or less drooping at their ends. The blackish-brown trunk bark, about three fourths of an inch thick, is irregularly broken by deep narrow furrows and rather wide, flat, scaly ridges. At first the smooth young twigs are pale yellow; they become yellowish or reddish brown and shining at the end of the first season and deep yellow-brown during the second summer.[40] The reddish-brown pointed, shiny winter buds, almost one fourth of an inch long, are somewhat curved toward the twig.

The leaves (fig. 37), thickish when full grown, are yellow-green, shiny above, bright silvery white beneath, and smooth on both surfaces, with conspicuously wide yellow midveins and large red-brown leaf stems. They vary in length from about 3¾ to 6 inches and in width from about one half to seven eighths of an inch. When the leaves appear they are accompanied by small, rounded, leaflike stipules at the base of the stem, which commonly disappear before the leaves are fully grown, but on vigorous shoots often persist until late summer. Among all of the tropical willows that occur in the United States, *S. bonplandiana toumeyi* is peculiar in its habit of not shedding its foliage in autumn. Most of the leaves fall irregularly

[40] This twig description evidently follows that of Sargent's Silva (*76, v. 9, p. 119*) for *Salix bonplandiana*, which reads as follows: "The branchlets are x glabrous, x light yellow at first, light or dark red-brown and lustrous at the end of their first season, and paler and orange-brown in their second year." Schneider (*81, p. 3*), a foremost present-day salicologist, keys out *bonplandiana* partly under the caption "ramuli annotini biennesque rubescentes vel purpurascentes." Field observations on this point appear to be needed.—W. A. D.

during the winter, but some may remain on the trees as late as February.

The short-stemmed staminate and pistillate flower clusters, borne in the axils of leafy twigs, are cylindrical in form, erect, and from about 1¼ to 1½ inches in length. Many of the staminate clusters are slightly longer than the pistillate. The male flowers usually bear 3 but occasionally 4 stamens, whose slender filaments, slightly hairy

FIGURE 37.—Foliage, flowers, and seed capsules of *Salix bonplandiana toumeyi*.. ×⅔.

at their bases, are entirely separate from each other. The rounded, thin, yellowish basal scales of both male and female flowers are minutely hairy on the outer surface and smooth on the inner surface or have only a few delicate hairs on the upper half. The rather long-stalked seed capsule is smooth, pale orange-yellow, and about one fifth of an inch long.

Nothing is now known regarding the characteristics of the wood.

### OCCURRENCE AND HABITS

So far as is now known (fig. 38) *S. bonplandiana toumeyi* extends into the United States only as far as southern Arizona and south-

FIGURE 38.—Geographic distribution of Toumey willow (*Salix bonplandiana toumeyi*).

western New Mexico. There it grows in gravelly, rocky soils along the borders of mountain streams at elevations of about 2,500 feet.

### LONGEVITY

Nothing is known definitely regarding the age attained by this willow.

## WESTERN BLACK WILLOW (SALIX LASIANDRA BENTH.)

### COMMON NAME AND EARLY HISTORY

*S. lasiandra* is frequently known throughout its range as black willow, evidently because of the very dark-brown or blackish trunk bark. But since the name black willow has been so long and properly applied to *S. nigra*, the writer has preferred to call this species western black willow, a name which was first taken up in 1908 (*19, p. 190; 85, p. 219*). In California, *S. lasiandra* is called yellow willow and waxy willow (*47, p. 175*), because the "one-winter-old" twigs are yellowish. But as the color of the twigs may vary from yellowish to dark purple, these names appear to be inappropriate.

In the first published account (*41, p. 159*) of the western black willow, the name *S. hoffmanniana* Smith was given it, on the supposition that this American willow was a form of the European *S. hoffmanniana* J. E. Smith, published in 1817. The specimens forming the basis for this designation were stated to have been collected at San Francisco, and a few at Monterey Bay, in 1827.

Specimens from which Bentham (*13, p. 335*) described and named this tree *S. lasiandra* in 1857 were collected by Hartweg along the Sacramento River in California, at a point, according to Jepson (*47, p. 176*), between Sacramento and Marysville. In 1842 Nuttall (*61, v. 1, p. 58*) described and named a large-leafed form *S. speciosa* (neither *S. speciosa* Host nor Hook. & Arn.). In 1859 Lyall found this large-leafed form of *S. lasiandra* on Vancouver Island (*7, p. 34*) and Andersson named it *S. lancifolia* (not *S. lancifolia* Doell). In 1868 Andersson (*8, p. 205*) named the same form *S. lucida β macrophylla* (not *S. macrophylla* Kerner). When, in 1895, it was discovered that all these specific and varietal designations were preoccupied for other willows at the time that they were applied to this large-leafed form of *S. lasiandra*, Sargent (*76, v. 9*) named it *S. lasiandra* var. *lyallii* in honor of Dr. Lyall, who at that time was supposed to have discovered the form. It would seem, however, that credit for having first recorded the existence of this variety belongs to Nuttall, whose observations and definite account of the tree in Oregon under *S. speciosa* preceded Lyall's discovery of it by 25 or more years.

A varietal form of the western black willow, found mainly in the Rocky Mountain region, is *S. lasiandra β caudata* (Nutt.) Sudw. (*84, p. 43;* see also *12, pt. 2, p. 372*). This form was first described (*61, v. 1, p. 61*), under the name *S. pentandra caudata* Nutt., the author supposing it to be an American form of the Old World *S. pentandra*. In 1858 Andersson (*5, p. 115*) named this form *S. fendleriana*.

Authors differ greatly in their judgment as to what constitutes the species *S. lasiandra* Benth. and the three varietal forms *S. lasiandra caudata* (Nutt.) Sudw., *S. lasiandra lancifolia* Bebb, and *S. lasiandra lyallii* Sarg. In his various writings, Sargent maintained the species and the first two varieties.

In 1898 Heller (*35, p. 580*) designated *S. lasiandra* var. *lyallii* Sarg. as *Salix lyallii* (Sarg.) Hell., and 2 years later (1900) he maintained *S. lasiandra caudata* (Nutt.) Sudw. (*36, p. 19*). In 1908 Britton and Shafer (*19, p. 190*) held *S. lasiandra* Benth. to include *S. pentandra caudata* Nutt. and *S. fendleriana* Anderss.,

and accepted Heller's promotion of *S. lasiandra* var. *lyallii* Sarg. to specific rank as *S. lyallii* (Sarg.) Hell. Recently also Rydberg (*71, p. 191*) accepted the latter designation but held *S. lasiandra caudata* (Nutt.) Sudw. to be a synonym of *S. fendleriana* Anderss. Under the present rules of nomenclature the latter name, which is the oldest applicable binomial, must be applied to this plant if it be considered a species. In the second edition of his manual, Sargent appears to have absorbed *S. lasiandra* var. *lyallii* Sarg. under *S. lasiandra.* Ball concurs in this disposition of the Lyall willow, the extremely wide and long leaves of which appear to be connected with the typical form of *S. lasiandra* by many intermediate leaf forms. Moreover, no floral or fruit characters found separate this supposed variety from the species.

In the writer's opinion it is advisable to follow Sargent (*79*) and maintain with *S. lasiandra* its two distinct varieties *S. lasiandra caudata* and *S. lasiandra lancifolia.*

### DISTINGUISHING CHARACTERISTICS

In parts of its range *S. lasiandra* is hardly more than a shrub, but elsewhere it sometimes reaches heights of 40 or 60 feet and a diameter of 24 to 30 inches. Ordinarily, however, it is about 25 or 30 feet in height and 12 to 14 inches in diameter.

The bark of medium- and large-sized trunks is about three fourths of an inch thick and very dark brown, with a pale-reddish tinge that is most marked in the little-exposed shallow fissures. The wide flat ridges of the bark are distinctly cut by cross seams into plates longer than they are wide. The short, rarely straight trunk bears long, straight, upright branches which form a narrow, open, unsymmetrical crown. Mature twigs are rather large and vary in color from clear reddish brown to yellow-brown; when very young the twigs are more or less hairy and are often covered with a whitish bloom. The ovate, pointed winter buds, about one fourth inch long, are a shiny chocolate-brown.

The long-pointed leaves of *S. lasiandra* (fig. 39) range in length from about 2 to 4¾ inches and in width from about one half to three fourths of an inch. The largest leaves usually are produced at the ends of vigorous shoots. In occasional trees leaves throughout the crown are from 7 to 12 inches long and 2 inches wide. When the leaves are mature the upper surface is deep yellow-green and shiny, and the lower surface is pale bluish green. The margins of the leaves are finely cut into very small gland-tipped teeth. The yellowish smooth or hairy leaf stems are from one fourth of an inch to 1 inch long and are provided with several rather conspicuous blackish glands at the point where they are joined to the base of the leaf.

A pair of minutely toothed, leaflike, half-moon-shaped stipules are produced at the base of each leaf stem. These are much larger on vigorous shoots, where they often remain with the leaves much of the summer, whereas the smaller stipules found elsewhere usually fall from the plant earlier. Staminate and pistillate flower clusters, borne on somewhat hairy, leafy twigs, are from about 1½ to 3 inches long, and the staminate clusters are almost twice as thick as the pistillate clusters. Staminate flowers bear 5 to 9 stamens on slender filaments which are minutely hairy at their bases. The ripe

seed capsules, borne on short pedicels, are from one fifth to one fourth of an inch long, smooth, and pale reddish yellow.

The varietal form *S. lasiandra caudata* (Nutt.) Sudw. (western black willow) is distinguished by its thicker, more leathery, some-

FIGURE 39.—*Salix lasiandra: A,* Pistillate spray; *B,* fertile twig with ripe ament, the seed about to disseminate. ×½.

what smaller leaves which are conspicuously "tailed" at the tip, more or less slightly scythe-shaped, and usually green on both sides or

only slightly paler beneath. The twigs of this variety are yellow and the winter buds are large and sometimes hairy on the lower part. The male catkins are relatively shorter and thicker than in typical *S. lasiandra*, and the scale at the base of each flower is usually toothed only at the top. As a rule also this variety is a smaller tree than is the typical *S. lasiandra*.

*S. lasiandra lancifolia* Bebb differs from *S. lasiandra* in the brownish or grayish hairiness on the twigs during the first season

FIGURE 40.—Geographical distribution of western black willow (*Salix lasiandra*).

(sometimes also during the second season) and on the lower side of immature leaves.

The heartwood of *S. lasiandra* and its varieties is pale brown, and the thick layer of sapwood is nearly white. When thoroughly seasoned a cubic foot of the wood weighs from 28 to 30 pounds (*15*). The wood has a characteristic soft, brittle texture. Locally it is sometimes used for fuel and for charcoal. The long slender annual

shoots, particularly those from the pollarded trunks, are tough and suitable for coarse grades of baskets. It is related (*47, p. 176*) that in the days of Alta California the trees of Spanish saddles were made from selected pieces of western black willow and red willow.

OCCURRENCE AND HABITS

*S. lasiandra* and its varieties have a range extending roughly from the valley of the Yukon River southward through the coast region and mountain ranges to southern California and southward from

FIGURE 41.—Geographical distribution of the Rocky Mountain variety of western black willow (*Salix lasiandra caudata*).

Washington to the central Rockies and into New Mexico (figs. 40 and 41).

They occur on the borders of streams, water holes, and lakes, in moist sandy and gravelly soils, growing singly or forming small, scattered groups. The vertical range is extensive, from about 50 feet above sea level in the California coast region to 4,500 feet in the northern Sierras and 8,500 feet in the southern Sierras; but everywhere abundant soil moisture is a requisite. The largest trees occur at the lower elevations. All bear seed abundantly, but reproduction is always rather scattered.

#### LONGEVITY

Very little is known at present regarding the age limits of *S. lasiandra* and its varieties. It is probable, however, that maturity is reached within about 50 years. Trees from 12 to 18 inches in diameter are from 30 to 47 years old.

### SANDBAR WILLOWS

As originally defined, several similar forms of very narrow-leaved willows were included under *S. longifolia* Muhl., published in 1803 (*60*), and this name served from 1803 to 1895 to designate what was considered a variable species of wide geographic range. The common names applied to *S. longifolia* were sandbar willow and longleaf willow. In 1895, however, Sargent (*74, p. 463*) showed *S. longifolia* Muhl. to be preoccupied, Lamarck having published the name *S. longifolia* in 1778 for a European willow perhaps identical with *S. viminalis* L. Sargent believed at that time (1895) that Nuttall's name *S. fluviatilis*, published in 1842 (*61, p. 73*), was the next oldest name for these willows and should be adopted. Nuttall's common name for them is river willow, in allusion to their common habit of growing along streams.

In 1900 Rowlee proposed a revision of western willows, in which all the forms previously referred to *S. longifolia*, and later to *S. fluviatilis*, were segregated as four distinct species, as follows: *S. fluviatilis* Nutt., *S. interior* Rowlee (*67, p. 253*), *S. exigua* Nutt., and *S. argophylla* Nutt. The characteristics relied upon to distinguish these species are not such as to be easily appreciated nor, in the writer's opinion, are they so fully dependable for the purpose of identification as could be desired. In point of stature these segregates are characterized respectively as "tree or large shrub" (*S. argophylla*); "a low shrub to a small tree" (*S. interior*); "low slender shrub to a small tree" (*S. fluviatilis*, *S. exigua*). The silvical habits of all appear to be rather similar.

The next event in the botanical history of what are here called the sandbar willows occurred in 1901 when Rydberg (in Britton, *17, p. 316*) maintained *S. fluviatilis* Nutt., to which were added as new species *S. luteosericea* Rydb. and *S. linearifolia* Rydb. The first of these two species was described in 1842 by Nuttall as *S. exigua*, and later (1896) designated by Sargent as *S. fluviatilis exigua* (*76, v. 9, p. 124*). The latter is a form of *S. interior* Rowlee published in 1900. In 1908, Britton and Shafer (*19, pp. 193–195*) took up *S. interior* Rowlee, citing as a synonym of it *S. fluviatilis* Sarg. (not Nutt.), and adding that—

> *Salix fluviatilis* Nuttall, to which this plant has been referred by some authors, described originally from Oregon or Washington, appears to be distinct from it and is not known to us to become a tree.

Britton and Shafer also took up *S. exigua* Nutt. and cited *S. fluviatilis exigua* Sarg. and *S. luteosericea* Rydb. as synonyms. They likewise maintained *S. sessilifolia* as distinct from other forms of the sandbar willow of Nuttall, and considered *S. argophylla* Nutt. and *S. fluviatilis argophylla* (Nutt.) Sarg. as synonyms. More recently (1913) Britton and Brown (*18, pp. 594–595*) continued the maintenance of *S. exigua* Nutt. and *S. interior* Rowlee, as the senior author did in 1908.

The next disposition of the variable forms originally referred to *S. longifolia* and later to *S. fluviatilis* Nutt. is by Rydberg (*71, p. 192*) who distinguishes five species—*S. exigua* Nutt., *S. stenophylla* Rydb. (*70, p. 271*), *S. interior* Rowlee, *S. linearifolia* Rydb., and *S. argophylla* Nutt.

In the writer's present judgment the arborescent narrow-leafed willows, heretofore called sandbar willows and occurring within the Rocky Mountain region, are held to constitute two distinct species, as discussed below under the headings *S. interior* Rowlee and *S. exigua* Nutt.

### SALIX INTERIOR ROWLEE [41]

#### COMMON NAME AND EARLY HISTORY

*S. interior* is commonly called sandbar willow, longleaf willow, narrowleaf willow, and river-bank willow.

It is difficult to trace the early history of this willow. In his original description of it as *S. longifolia*, Muhlenberg (*60, pp. 238–239*) gives "Habitat ad Susquehannam," showing that the type specimen came from the East, presumably prior to 1803. It seems probable that Nuttall first found it in the Missouri and Mississippi River bottoms some time previous to 1842, for he says (*61, v. 1, p. 73*) in speaking of *S. fluviatilis*: "We believe this is also the same Willow that we mistook for the Long-leaved species of Pursh and Muhlenberg (*Salix longifolia*), which so commonly lines the banks of the Missouri and Mississippi. . . ."

#### DISTINGUISHING CHARACTERISTICS

This willow is very commonly a slender-stemmed shrub from 4 to 8 feet in height. Less frequently it becomes a small tree from 15 to 20 feet high and from 2 to 6 inches in diameter. Exceptional trees are sometimes from 40 to 60 feet high and 1 or 2 feet through. The trunk bark, dull brown and sometimes slightly reddish, is comparatively smooth with small, irregular close scales. The slender twigs are smooth and during the first season are yellowish or sometimes dull reddish yellow. The mature, very narrow leaves (fig. 42) are finely and distinctly toothed; they are from about 2 to 5½ inches long, or slightly longer, and vary in width from about three sixteenths to one third of an inch. They are smooth on both surfaces and are pale yellowish green, which is of a lighter shade on the lower surface. The channeled leafstalks are from about one eighth to one fourth of an inch long. The cylindrical staminate and pistillate flower clusters are finely hairy and are borne on leafy twigs, the staminate flowers at the end of the twig or in the axils of leaves, and the pistillate flowers terminating the twig. The staminate clusters are approximately 1 inch long and one third of an inch in diameter, and the pistillate clusters vary from 1½ to 3 inches in length

[41] This name is substituted for *S. longifolia* Muhl., which the author in his uncompleted manuscript had designated for "sandbar willow", following the precedent of the Check List (*90, p. 71*). Since Mr. Sudworth has just pointed out in the above text that *S. longifolia* is a homonym (preempted by the 25-year-older *S. longifolia* Lam. of Europe) and is therefore absolutely untenable botanically, it seems unwise to perpetuate here an error that the author himself, given full opportunity for the revision of his manuscript, would doubtless have corrected. The name *S. interior* Rowlee is now generally adopted by botanists to replace *S. longifolia* Muhl.—W. A. D.

and are about one fourth of an inch thick. The mature pale-brown smooth or woolly seed capsules are nearly one fourth of an inch long.

FIGURE 42.—Fruiting spray of *Salix interior*. ×1.

The sapwood is thin and is pale grayish white, and the heartwood is pale reddish brown. In texture the wood is rather firm; when thoroughly seasoned a cubic foot of it weighs about 30 pounds. It is rarely used for any purpose.

OCCURRENCE AND HABITS

*S. interior* (fig. 43) grows almost entirely on the periodically overflowed sand banks and mud banks of ditches, streams, ponds, and lakes, where, according to the space available, it forms large or small dense thickets of pure growth. It is one of the first woody plants to establish itself on the shifting sand and mud bars. These growths are rapidly extended by shoots from running rootstocks, which increase the density of the seeded stand. In some instances these thickets are almost impenetrable. The effects of their sand- and mud-binding qualities are often seen in broad, low river bottoms where the thickets effectively retain the shifting sand and silt bordering the water channel and form strips of permanent land. The density of the growth usually excludes all other plants. *S. interior* is very intolerant of shade, rarely growing in the imme-

FIGURE 43.—Geographic distribution of sandbar willow (*Salix interior*).

diate shade of other willows and cottonwoods and commonly producing a long, clean, canelike trunk surmounted by a narrow little-branched crown.

LONGEVITY

Little is known now regarding the age limits of this willow. Its shrubby form is rather short-lived, especially where it stabilizes the land, allowing the growth there of cottonwoods and large willows which soon crowd it out. Trees from 2 to 3 inches in diameter are from about 10 to 14 years old. The largest trees doubtless attain their maximum growth in 40 to 50 years.

The following varietal forms of *Salix interior* Rowlee are distinguished:

*S. longifolia angustissima* Anderss. (*7*),[42] which ranges from northwestern Texas through northeastern and southern New Mexico, is distinguished from the species by the absence of a dorsal gland in the staminate flower and by the silky hairiness of the young ovary.

*S. interior pedicellata* (Anderss.) Ball[43] occurs from western South Dakota and northwestern Wyoming into eastern Montana, Saskatchewan, and Alberta to the Yukon River (vicinity of Dawson). It is distinguished from the species by its extremely narrow leaves, smooth ovaries, and longer pedicels of the seed capsules.

### SALIX EXIGUA NUTT.

#### COMMON NAME AND EARLY HISTORY

This species, termed here narrowleaf willow, is probably not popularly distinguished from *S. interior*, which it resembles in general appearance. Nuttall called it slender willow, first describing it in 1842 under its present name, *S. exigua* (*61*). Later it was made a variety of "*S. longifolia*", being designated in 1880 as *S. longifolia* var. *exigua* Bebb (in Brewer, Watson, and Gray, *16*, *v. 2*, *p. 85*) and in 1896 as *S. fluviatilis* var. *exigua* Sarg. (*79*).

*S. exigua* Nutt. was probably first discovered by Nuttall (*61*, *v. 1*, *p. 75*), for he says of it:

> This species is also a native of the territory of Oregon and grew with the preceding [i.e., *S. fluviatilis*], which it strongly resembles. * * * The male plant I have not seen.

#### DISTINGUISHING CHARACTERISTICS

*S. exigua* is for the most part a very slender reedlike shrub from 4 to 6 feet high, but in eastern Washington on the borders of the Palouse and other streams it becomes a small slender-stemmed tree 18 to 20 feet in height and 3 to 6 inches in diameter. The form found in the Rocky Mountain region is at best only a tall shrub. The trunk bark is dull grayish brown and nearly smooth or only slightly furrowed on the larger trunks. The crown, composed of a few slender branches, is similar to that of *S. interior*. The delicate twigs are smooth and brownish, tinged with red. The narrowly lance-shaped mature leaves, tapering at both ends, vary in length from 2 to 3 inches and in width from one eighth to one fourth of an inch (fig. 44). They are bluish green, smooth on the upper surface and coated with white silky hairs on the lower surface, and the borders of the leaves are minutely toothed, mostly above the middle. The staminate and pistillate flowers, which are usually terminal on smooth leafy twigs but are sometimes borne also in the axils of the upper leaves, are from about 1 to 2 inches long and are narrowly cylindrical. Scales of the flowers are white

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[42] Although this varietal name is unfortunately untenable, because of the homonymity of the specific name already explained, the logically consistent combination would appear to be *S. interior angustissima* (Anderss.). As given above, this name follows the form in the Check List (*90*, *p. 71*). Strictly speaking, however, Andersson's name (*7*, *p. 55*) is *Salix longifolia* Muhl. * * *argyrophylla* (Nutt.) Anderss. —— *angustissima* Anderss., indicating this form as a variety of the subspecies, and hence a quadrinomial.—W. A. D.

[43] In the author's manuscript this appears as *S. longifolia pedunculata*, which accords with the Check List (*90*, *p. 71*). However, since I have been unable to locate this name, I have assumed that it is a slip for *S. longifolia pedicellata* Anderss. (*7*, *8*).—W. A. D.

and woolly and the filaments of the two stamens are hairy on the lower half. The pointed, stemless seed capsules are smooth.

Wood of *S. exigua* is indistinguishable from that of *S. interior*.

OCCURRENCE AND HABITS

The range of *S. exigua* is a western complement of that of *S. interior* (fig. 45). For botanical reasons these two species must be

FIGURE 44.—Foliage and fertile catkins of *Salix exigua*. ×⅓.

held distinct, but in the writer's opinion they are so similar in their silvical habits that they could as well be treated as one. *S. exigua*, seeding abundantly and also readily establishing itself from rootstocks, comes up in a crowded mass of seedlings that are the first woody growth to occupy wet sand bars and muddy shores of streams, ponds, and lakes. Its preference is for moist or wet sand and gravel, often overlain with silt. In such soil the network of running roots forms an excellent binder, holding these favorable but too easily

erodible bars and banks in place until, more slowly, cottonwoods and other valuable lowland trees can become established. Often these pure, dense thickets of narrowleaf willow grow up into strikingly even-aged stands characterized by small crowns and long,

FIGURE 45.—Geographic distribution of narrowleaf willow (*Salix exigua*).

reedlike, clear stems. Despite its crowded character of growth, this willow is intolerant of overhead shade in all stages.

### LONGEVITY

*S. exigua* is probably short-lived. Stems from 2 to 3 inches in diameter are from 9 to 14 years old; the largest are probably 50 years old, at least.

## YEWLEAF WILLOW (SALIX TAXIFOLIA H.B.K.)

### COMMON NAME AND EARLY HISTORY

*S. taxifolia*, though little known to many, is perhaps one of the most distinctly marked of all native tree willows because of its small, very narrow leaves. Settlers know it only as "a variety of willow." The name yewleaf willow, here adopted, is a book name coined from the tree's specific name, *taxifolia*, in allusion to its yewlike leaves.

The yewleaf willow appears to have become known to travelers first through plants growing in Mexican gardens, as Humboldt, Bonpland, and Kunth indicate (*45, p. 22*) in their note: "Colitur in hortis Mexici, Queretari, Zelayae, alt. 900–1,200 hex."

Specimens of *S. taxifolia* were first collected in the United States near El Paso, Tex., in 1849 (*76, v. 9, p. 129*) by Wright, and later, in 1883, Pringle found it in the vicinity of Tucson, Ariz., and again in canyons of the Santa Catalina Mountains in Arizona. Sargent (*76, v. 9*) further reports that Toumey found it in 1894 in similar situations in the Santa Rita and Swissholm Mountains of Arizona. In 1924 the author found it in the Davis Mountains in Texas. In 1817 it was first technically described and named *S. taxifolia* by Humboldt, Bonpland, and Kunth (*43, v. 2, p. 22*), and this name has been generally maintained to the present time. In 1831 Schlechtendal and Chamisso (*80, p. 354*) described and named what the writer regards as a form of *S. taxifolia* under the specific name *Salix microphylla* Schlecht. and Cham., which Schneider in 1918 (*81, p.* 24) designated as *S. taxifolia* var. *microphylla* (Schlecht. and Cham.) C. Schn., stating that its range is from central Mexico to Guatemala and Puerto Rico. In 1867 Andersson (*7, p. 57*) distinguished two varietal forms as *S. taxifolia* var. a *sericocarpa* and *S. taxifolia* var. b *lejocarpa*, but these forms have not been satisfactorily identified and are not now recognized by American botanists.

### DISTINGUISHING CHARACTERISTICS

*S. taxifolia* ordinarily attains a height of 30 to 40 feet and sometimes 50 feet, and a diameter ranging from 12 to 18 inches. It has a rather widespreading, round, open crown, and the mid-crown and lower-crown branches are conspicuously long and weeping. The trunks are more or less crooked and are clear of branches for one third to one half of their length. The rough, pale brownish-gray bark is about an inch thick and is broken by rather deep, narrow furrows and wide flattish ridges which have very small, closely attached scales. The main ridges are connected by diagonally disposed smaller ones. During most of the first season the very slender twigs are covered with grayish woolly hairs, which are usually shed toward the close of the season, exposing the pale red-brown bark. The mature pointed buds are also covered with fine hairs. Fully mature leaves are a pale gray-green. Young leaves are covered on both sides with fine, soft, whitish hairs, which as the leaves become full grown disappear almost entirely from the upper surface but never completely from the lower side. The borders of the

leaves are mostly entire, only occasionally having very small indistinct teeth. Foliage of this willow is conspicuously smaller than that of any other native arborescent species (fig. 46). Both kinds of flower clusters are borne at the ends of short, slender, leafy twigs

FIGURE 46.—Foliage, flowers, and seed capsules of *Salix taxifolia*. ×½.

(fig. 46). The twigs bearing the staminate clusters grow from the axils of large leaves on the main stems. Male flowers bear two stamens, the slender filaments being hairy toward their lower ends. The mature, rather long-pointed, reddish-brown seed capsules are hairy and are borne on very short pedicels.

The color, weight, and structural characteristics of the wood are at present unknown. The branches are used for brooms, and, very occasionally, the wood for fuel.

### OCCURRENCE AND HABITS

In its rather limited range (fig. 47) in southwestern United States, *S. taxifolia* occurs scattered sparingly in some sections and abun-

FIGURE 47.—Geographic distribution of yewleaf willow (*Salix taxifolia*).

dantly in others in the narrow bottoms and near the borders of mountain streams, at elevations ranging from about 3,200 feet to approximately 5,000 feet. Instances are recorded in northern Mexico of this tree reaching an altitude of 6,500 feet. The soil in which it grows is often a mixture of washed sand and gravel, which is sometimes overlain by rich adobe silt.

*S. taxifolia* produces an abundance of seed which is widely distributed by the wind and in some cases by flood waters. Many capsules with partly escaped seeds adhere to the trees as late as November. Reproduction is generally rather sparse but in some instances is exceedingly abundant, producing dense growths of seedlings, similar to those of sandbar and narrowleaf willows. More or less common associates of yewleaf willow at the upper limits of its vertical range are *Platanus wrightii* and *Juglans rupestris.*

*S. taxifolia* is very intolerant of shade during all stages of its growth.

#### LONGEVITY

Little is known now regarding the age limits of this willow. It is possible, however, that the largest trees are 80 to 125 years old.

### WHITE WILLOW (SALIX LASIOLEPIS BENTH.)

#### COMMON NAME AND EARLY HISTORY

*S. lasiolepis* is commonly called white willow,[44] probably because of the whitish (glaucous) undersurface of the leaves. The common name California white willow has also been proposed (*19, p. 198*) for this tree, but as its range is not wholly within California this name does not seem to be entirely appropriate. The name arroyo willow, in use by Jepson (*46*), Sargent (*79*), and Ball and Abrams (*2*) refers to a characteristic habitat of the species.

*S. lasiolepis* was discovered by the German gardener and collector of plants, Theodor Hartweg, along the Salinas and Carmel Rivers, near Monterey, Calif., in 1846 or 1847 (*13, pp. 294, 335*). Bigelow found it next near San Francisco, Calif., in 1854. It first became known to science in February 1857, when Bentham named it *S. lasiolepis* (*13, p. 335*). Three varieties, proposed by Bebb (in Brewer, Watson, and Gray, *16, v. 2, p. 86*) and Ball (*9a, pp. 436–437*), distinguished mainly by differences in the form and size of the leaves, have not generally been maintained by botanists. Jepson (*46, p. 340*) and Ball (in Abrams, *2, p. 497*) have, however, taken up *S. lasiolepis* var. *bigelovii* Bebb, which is the form Bigelow found near San Francisco in 1854. This form was originally named "*S. bigelovii*" by Torrey (*96, p. 139*).[45] This is the only other binomial that has been applied to this willow since it has been known to science.

#### DISTINGUISHING CHARACTERISTICS

At high elevations white willow forms a cluster of low shoots; at low elevations it is a tree 15 to 25 feet in height and 6 to 10 inches

[44] This name is in conflict with that in general use (*4*) for the original white willow (*Salix alba* L.) of Europe, now widely naturalized in the eastern United States through long cultivation and named in the Check List (*90*) "European White Willow."—W. A. D.

[45] Inasmuch as the Pacific Railroad report in which *S. bigelovii* Torr, was first published bears the title-page date 1856, it would at first appear that *S. bigelovii* is older by 1 year than *S. lasiolepis* Benth., published in 1857, and that it should replace the latter. As a matter of fact, however, Torrey's introduction to his part of the report bears the date January 12, 1857, and in describing other willows in this report Torrey refers to Bentham's Plantae Hartwegianae, published in 1857, in which *S. lasiolepis* Benth. was first published. It is clear, therefore, that the latter name is really the older.

in diameter. Exceptionally large trees are 30 to 40 feet high and 14 inches or more in diameter. The slender branches trend upward strongly, forming a rather narrow, irregular, open crown. The pale-brown or gray-tinged bark of larger trunks is less than half an inch thick and is shallowly seamed, the wide flat ridges being connected here and there by smaller lateral ridges. Occasionally light ashy

FIGURE 48.—Leafy spray of *Salix lasiolepis*. ×⅞.

gray areas also appear on the ridges. The smooth, unbroken bark of the large branches and of young trunks is pale gray. The mature, rather thick twigs of the season are deep red-brown, tinged with yellow toward their extremities, where they are sometimes very minutely downy, though elsewhere smooth. Young twigs are covered with a fine velvety down. Mature leaves (fig. 48) which are

2½ to about 5½ inches long and one half to 1 inch wide, are somewhat thick and leathery. They have yellow stems and midveins, and are dark yellow-green and smooth on the upper sides and very pale green or sometimes conspicuously silvery white beneath. They are more or less downy, particularly on the midveins and the lower surface of the less mature terminal leaves. The margins of the leaves are wavy and entire, but ocasionally bear minute widely spaced teeth. The erect flower clusters, both male and female, are cylindrical in form and are from 1¼ to 1½ inches long. They are densely flowered and are borne on very short hairy twigs, most of which

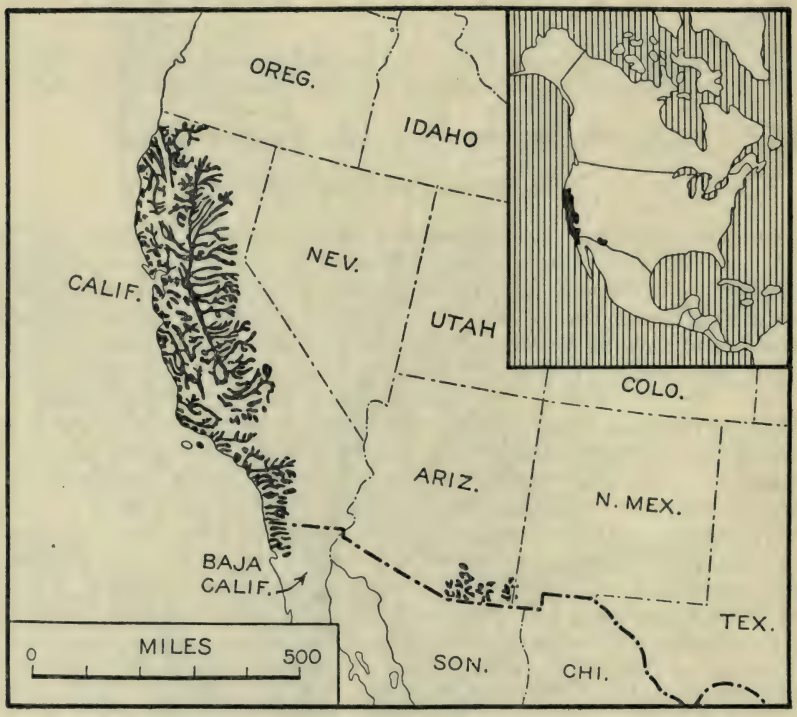


FIGURE 49.—Geographic distribution of white willow (*Salix lasiolepis*).

bear from 1 to 3 small leaves or early deciduous scales. The staminate flower clusters are about half an inch in diameter, the pistillate about one fourth inch. Each staminate flower bears two stamens, the smooth filaments being united below the middle. Mature seed capsules are pale reddish brown and about one fifth of an inch long, the catkins bearing them being about 2½ to 2¾ inches long.

The wood of white willow is narrow-ringed, soft in texture, rather brittle, and when dry weighs about 35¾ pounds per cubic foot. The whitish sapwood forms a much larger proportion of the bole of the tree than the brownish heartwood. In the southern part of its range, where fuel timber is scarce, the wood of this willow is used for fuel.

#### OCCURRENCE AND HABITS

*S. lasiolepis* (fig. 49) grows in moist sandy and gravelly soils, scattered individuals or small groups occurring on the borders of lowland streams and in adjacent bottoms, in springy places, and on streams of lower mountain slopes. Tree forms occur most commonly at lower elevations in the Pacific slope portion of the tree's range, shrubby forms being found only at higher elevations (3,000 to 4,000 feet). Little is known now regarding the silvical habits of this willow. In the southwestern part of the Rocky Mountain region it is often associated with *Alnus oblongifolia* and *Platanus wrightii.*

#### LONGEVITY

The age attained by *S. lasiolepis* has not been fully determined. Stems from 5 to 9 inches in diameter are from 12 to 22 years old. The largest trees are probably from 75 to 80 years old.

### MACKENZIE WILLOW (SALIX MACKENZIEANA BARR.)

#### COMMON NAME AND EARLY HISTORY

*S. mackenzieana* is probably not distinguished by laymen from other willows in its range. The book name of Mackenzie willow is known chiefly to botanists. Rydberg (*71*) has recently applied the common name diamond willow to it.

Information is lacking as to the exact locality where this willow was discovered. Richardson first found it in Canadian territory at the " Great Slave Lake and the Mackenzie River " (*39, v. 2, p. 149*) some time previous to 1833. It first became known to science in 1839, when Hooker published Barratt's manuscript name *Salix mackenzieana*[46] and his own variant of that, *S. cordata* γ *mackenzieana.* In 1858 Andersson (*5, p. 125*) described it as a hybrid, *S. cordata* × *vagans*, and 2 years later confirmed it (*6, p. 65*) as *S. cordata* × *vagans* (=*rostrata*), while in 1867 (*7, p. 160*) he questionably treated it as a valid species, *S. mackenzieana*, though still intimating its possible hybrid nature. In 1895 Bebb (*12, pt. 4, p. 473*) designated it as *S. cordata mackenzieana* Hook., as did also Sargent (*76, v. 14*) as late as 1902. In 1908 Britton and Shafer (*19, p. 196*) treated this willow as a distinct species, *S. mackenzieana* Barr., and this disposition was followed also by Rydberg (*71, p. 193*).

While *S. mackenzieana* is a little-known willow, possibly to be considered a variety of the widely distributed shrubby heartleaf willow (*S. cordata* Muhl.), it is here maintained as a distinct species. The extreme type of *S. mackenzieana* is apparently specifically distinct from *S. cordata* in the form of its leaves; nevertheless, if strict account is taken of the common intermediate forms that clearly connect *S. mackenzieana* with *S. cordata*, the maintenance of *S. mackenzieana* as a varietal form may appear advisable.

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[46] Hooker's spelling (*39, v. 2, p. 149*) is *mackenzieana* in the trinomial *Salix cordata mackenzieana*, which subsequent authors changed to *mackenziana.* The manuscript name *Salix mackenzieana* Barr. and that of *S. cordata mackenzieana* Hook. were published simultaneously (*39*), the latter having place priority in the line. Some botanists prefer to write the authority as "(Hook.) Barr.," but Mr. Sudworth's citation of Barratt as sole authority for *S. mackenzieana* is justifiable, as it seems more probable that Hooker changed Barratt's name than vice versa.—W. A. D.

DISTINGUISHING CHARACTERISTICS

*S. mackenzieana* is a slender, straight tree from 15 to 18 feet high and from 3 to 5 inches in diameter, with thin, smooth, unbroken ash-

FIGURE 50.—Foliage and seed capsules of *Salix mackenzieana*. ×½.

gray bark and a narrow, rather compact crown of thin branches which grow upward. The winter buds, which are about one eighth of an inch long, are bright reddish yellow. Mature twigs of the year are stiff, rather slender, and shiny yellow; during the second season they become greenish. When young the reddish twigs are

sometimes slightly hairy, particularly near the base. Mature leaves (fig. 50) are 1¾ to 3¼ inches long, smooth on both surfaces, and a deep yellow-green (paler beneath). The scythe shape of occasional leaves is a notable characteristic. The leaf margins usually show fine, although sometimes obscure, teeth, but are occasionally entire. Midveins and stems of the leaves are yellow. Kidney-shaped, veiny

FIGURE 51.—Geographic distribution of Mackenzie willow (*Salix mackenzieana*).

stipules are usually present during the first season. Staminate flowers bear two stamens on rather long, slender, smooth filaments. The smooth seed capsules are about one fourth inch long, pale reddish brown, and borne on rather long stems when mature. The structural and other characteristics of the wood are unknown.

### OCCURRENCE AND HABITS

*S. mackenzieana* (fig. 51) grows naturally along the borders of mountain streams in moist rocky and gravelly soils. Little is now

known regarding its silvical habits and associates, except that it is found with *S. monochroma* and *S. lutea.* Its climatic requirements and seeding habits and the conditions under which reproduction takes place most readily are also little known. Like other willows, it is doubtless intolerant of shade during all periods of its life.[47]

#### LONGEVITY

Nothing is known of the age of the largest trees. Small trees from 3 to 5 inches in diameter are from 13 to 22 years old.

### BEBB WILLOW (SALIX BEBBIANA SARG.)

#### COMMON NAME AND EARLY HISTORY

*S. bebbiana* is a common and widely distributed willow. Another book name for this species is beak willow, derived from the botanical *S. rostrata* Richards., formerly applied to this tree in allusion to the slender beaklike apex of the seed capsules. However, this technical name cannot be retained now, because at a still earlier date it was applied to another willow.

The botanical history of *S. bebbiana* began in 1823, when Richardson (*64, p. 753*) named and described this willow as *S. rostrata*, not knowing that in 1799 Thuillier had applied that name to an Eurasian willow which also had been previously named *S. repens* by Linnaeus. In 1868 Gray (*34, p. 464*) described and named *S. bebbiana* "*S. livida*, Wahl., var. *occidentalis*", under which name it was known to botanists for nearly 30 years. In 1895 Sargent (*74, p. 463*) called attention to the fact that *S. livida occidentalis* A. Gray was preoccupied by the West Indian willow, *S. occidentalis* Koch (published in 1828), leaving the species under discussion without a technical name. He therefore named it *Salix bebbiana.*

Exactly when, where, and by whom the Bebb willow was discovered appears to be unknown. The English captain, John Franklin, who headed the Franklin Expedition (*66*), in the course of whose explorations the tree was found, conducted his work during the years from 1819 to 1822, and this is the general date of discovery, for which credit probably belongs to Richardson, surgeon-naturalist of the expedition, the discovery probably taking place in the region of the species' greatest abundance, west of Hudson Bay.

#### DISTINGUISHING CHARACTERISTICS

*S. bebbiana* is commonly a shrub or small shrublike tree 8 or 10 feet high, but occasionally it becomes a tree 18 to 25 feet high and 4 to 8 inches in diameter. The clear trunk is short and the broad, rounded, dense crown is made up of slender branches which ascend sharply. The thin trunk bark is scaly and of a dull gray-green or reddish green. The bark of the twigs, which varies in color from

[47] Jepson has taken up in his Silva of California (*47, p. 180*) *S. cordata* var. *watsonii* Bebb, which he says occurs at elevations of 6,000 to 9,000 feet in "San Jacinto Mountain, northern Sierra Nevada, and eastward to Utah." The variety is characterized by smooth, polished yellow branches; smaller (1 to 3 inches long), oblong, short-acuminate, serrulate or subentire leaves; small or no stipules, and crowded catkins 1 inch long.

purple to reddish brown, is at first very hairy but becomes smooth during the first winter.

Mature leaves (fig. 52, *C*) are thick. On the upper surface they are dull green, veiny, and usually smooth but occasionally minutely hairy; on the under surface they are whitish or pale green, coated with minute hairs, and conspicuously net-veined. When old, some of the leaves may be nearly or entirely smooth on both sides. The

FIGURE 52.—Foliage, flowers, and seed capsules of *Salix bebbiana: A*, Fruiting spray, with capsules; *B*, staminate twig; *C*, twig with mature leaves; *D*, young shoot with leaves. ×⅔.

hairiness is particularly pronounced along the midribs and veins, and late in the season the hairs may become pale yellowish brown. The leaf margins are usually somewhat wavy and beset irregularly with mostly distant, often incurved teeth; frequently only the terminal portion of the leaf is toothed, and occasional leaves are entire. The leaves range in length from about 1½ to 3 inches and in width from about one half to 1 inch. The reddish, hairy leaf stems are

from one fourth to one half of an inch long. On vigorous shoots (fig. 52, *D*) the half-heart-shaped, leaflike stipules at the base of the leaf stems are sometimes almost one half of an inch long and have gland-tipped teeth on their margins.

The catkins come forth with the leaves and are then from about three fourths to 1 inch in length. Two stamens are borne by the staminate flowers, the filaments of the stamens having no hairs. Flowers of both sexes bear a tiny minutely hairy scale at each flower base; in the pistillate flowers this scale persists until the seed capsules are ripe. Mature seed capsules (fig. 52, *A*) are borne in loose

FIGURE 53.—Geographic distribution of Bebb willow (*Salix bebbiana*).

clusters and have long, beaklike points and slender pedicels often about one half of an inch long.

Nothing is known now regarding the characteristics of the wood.

### OCCURRENCE AND HABITS

*S. bebbiana* (fig. 53) grows in moist sandy or gravelly soils rich in humus. It occurs near streams, lakes, and ponds, and frequently in the vicinity of perpetual springs. It is very abundant throughout the Northern States, and especially so in its far-northern range in Canada. Richardson, the probable discoverer of this willow, mentions it (*65, p. 313*) as one of the two commonest willows in Rupert's Land and in the far north, stretching in all directions in great, impenetrable thickets 20 or more feet in height. Richardson also states that he traced this species "from Lake Superior to the Arctic Circle, or beyond it." Bebb willow is less abundant and more or

less widely scattered in the Rocky Mountain region where, as a slender, many-stemmed shrub, it reaches elevations of 8,500 to 10,000 feet. In its range it descends to within a few hundred feet of sea level.

*S. bebbiana* bears seed abundantly. It reproduces itself both by seed and root sprouts. When growing in dense thickets the production of long, slender stems with small crowns indicates that it is not tolerant of shade.

#### LONGEVITY

Nothing is known regarding the age attained by this willow. It is probable, however, that mature trees are produced within 50 or 60 years.

### SCOULER WILLOW (SALIX SCOULERIANA BARR.)

#### COMMON NAME AND EARLY HISTORY

*S. scouleriana* is usually called simply willow, black willow, or occasionally mountain willow, because it grows at rather high elevations. Another name in frequent use is fire willow, because of its invasion of burned-off areas. The earliest book name for this species is "blunt-leaved willow", applied to it in 1842 by Nuttall (*61*). For the most part, however, it has been known to botanists during the last 20 years as Nuttall willow, this name having been coined from the technical name *S. nuttallii* Sarg., which was applied to the species in 1895 (*74*). Scouler willow first became known to botanists in 1839 when Hooker published Barratt's original diagnosis of *S. scouleriana* (*39, v. 2, p. 145*). Apparently American writers did not, until quite recently, recognize this as the first technical name applied to the plant, for it was long and widely known as *S. flavescens* (*61*). In 1895 Sargent (*74, p. 463*) showed that Nuttall's *S. flavescens* is antedated by *S. flavescens* Host, published in 1828, which is now held to be a synonym of Linnaeus' *S. arbuscula*, published in 1753. Not being aware of its true name and assuming that the tree had had no tenable technical name for more than 50 years, Sargent renamed it *S. nuttallii*. The true connection of the name *S. scouleriana* Barr. with this willow appears to have been fully understood only somewhat later.

In 1896 the Pacific slope form of Scouler willow was segregated as a variety, *S. nuttallii* var. *brachystachys* (Benth.) Serg. (*76, v. 9, p. 142*), based on *S. brachystachys* Benth. (*13, p. 336*), to which the author referred as a synonym *S. scouleriana* Barr. (in part). Jackson (*44, pp. 780, 785*) has accepted *S. brachystachys* Benth., published in 1857, for this willow.

Scouler willow, as found throughout its wide range in the Pacific slope and Rocky Mountain regions, is exceedingly variable in the size and shape of its leaves. Although fairly dependable characters allow the distinguishing of two varieties, a central and southern California form and a Sierra and Rocky Mountain form, it might be best not to consider this distinction and to regard the whole as one variable species. Without considering possible varietal distinctions, there is a peculiarly close general resemblance in the habit of the trees and in their leaves as found from the Pacific slope to the Rocky Mountains.

In his treatment of Scouler willow (*47, p. 180*) Jepson states that he is unable to distinguish, even varietally, the California coast region form from the one found in the Sierras. Likewise, Ball (in Abrams, *2, p. 505*) terms this willow " an immensely variable species especially as to foliage. To attempt to distinguish varieties

FIGURE 54.—Leafy spray of *Salix scouleriana*. ×⅛.

here would add to confusion." Sargent (*79, p. 161*) distinguished two varieties, *S. scouleriana* var. *erassijulis Anderss.*[48] (syn. *S. brachystachys* Benth.), which occurs from central California to San Bernardino County, and *S. scouleriana* var. *flavescens* C. Schn. (see footnote 50, page 96) which occur from the Sierras to the Rocky Mountains of Colorado and northern New Mexico, northern Wyoming, and the Black Hills of South Dakota.

[48] The Check List (*90, p. 73*) cites Andersson as the authority for this variety. However, Andersson's name (*8, p. 225*) was *Salix brachystachys* Benth. (subsp.) *β scouleriana* (Barr.) Anderss., var. *crassijulis* Anderss. The correct citation is *S. scouleriana* (var.) *crassijulis* (Anderss.) C. Schn. (*82, pt. 9, p. 12*).—W. A. D.

The central and southern California form of Scouler willow, first described in 1857 as *S. brachystachys* Benth. was, according to Bentham (*13, p. 294*) first collected by Hartweg in 1846–47 in woods near Monterey, Calif. The northern Pacific slope form, first described in 1839 as *S. scouleriana* Barr., appears to have been col-

FIGURE 55.—Geographic distribution of Scouler willow (*Salix scouleriana*).

lected first by Scouler in "North West America, on the Columbia", probably about 1836 or 1837.

Scouler willow appears not to have been introduced into English and European gardens. On the Pacific coast, particularly in Oregon and Washington, it is occasionally cultivated as a shade and ornamental tree in lawns and public parks. It serves excellently for these purposes, because of its handsome varied foliage and symmetrical crown.

DISTINGUISHING CHARACTERISTICS

The trunk of the typical tree form of Scouler willow is single and usually straight and upright, but sometimes crooked or variously bent. When grown in the open the long, slender, somewhat drooping branches form a rather close, elongated crown which is shortest in trees growing in dense stands. The clear trunk is very short. The usual height of the tree form is about 20 to 30 feet, and the diameter 6 to 10 inches. At high altitudes it is only a shrub. The thin bark of large trunks is irregularly broken into wide ridges at the base of the trunk and is dark brown, with a faint tinge of red, which is present also on smoother parts of the trunk.[49] Twigs of 1 or 2 seasons' growth are stout and clear reddish yellow, becoming deep mahogany brown with age.

The shape and texture of the leaves (fig. 54) serve generally to distinguish Scouler willow from other willows associated with it. When mature the leaves are from about 1½ to 4 inches in length, firm, thickish, and somewhat shiny and smooth. They are deep yellow-green on the upper surface, and pale or whitish and sometimes very minutely hairy beneath. The prominent yellow midveins, as well as the leaf stems, are finely hairy. The margins of most leaves are entire and are thickened and slightly curled toward the under surface, but some leaves are remotely and very shallowly cut into round-pointed teeth. The early matured leaves are accompanied by glandular-toothed leaflike stipules at the base of each leafstalk, are crescent-shaped, about one fourth of an inch long, and usually fall in late summer, except those on vigorous new shoots, which may remain much longer.

The flower clusters, which appear before the leaves, are erect and on very short pedicels. The staminate clusters are about 1 inch long and one half of an inch thick and the pistillate clusters about 1½ inches long and nearly an inch thick. The staminate flowers are subtended by a small, minutely hairy scale, and bear two stamens on smooth slender filaments. The clusters of mature seed capsules are erect and about 2½ to 3 inches long; the long-pointed, hairy seed capsules are pale brown, about one third of an inch long, and are borne on very short pedicels.[50]

Wood of the Rocky Mountain form of Scouler willow is pale reddish brown and of somewhat lighter weight than that of the Pacific slope tree, which is slightly more reddish. The whitish sapwood of both forms is very thick, and the wood of both is narrow-ringed. When dry the wood of the Rocky Mountain tree weighs about 31 pounds per cubic foot. The wood is not commercially

[49] The varietal form of this willow, *S. scouleriana crassijulis* Anderss. (=*S. brachystachys* Benth.), found in central California and southward, is generally a larger tree than the Rocky Mountain form and has a longer clear trunk and ashen-gray bark with whitish areas, which when broken shows clear red-brown.

[50] *S. scouleriana flavescens* C. Schn., a varietal form which occurs from the California Sierras to the central Rockies and the Black Hills of South Dakota, is characterized by its yellowish-green twigs and yellowish-green obovate-rounded leaves. The Check List (*90, p. 73*) cites Schneider as sole authority for this variety. The correct citation is *Salix scouleriana flavescens* (Nutt.) J. K. Henry (*38, p. 98*), based on *S. flavescens* Nutt. (*61, p. 65*). Schneider, however, seriously questions whether Henry's plant is the same as Nuttall's (*82, pt. 9*) and, therefore, proposes for Henry's form first the varietal name *S. scouleriana poikila* C. Schn. (*82, pt. 9, p. 12*) and later the formal name *S. scouleriana* f. *poikila* C. Schn. (*82, pt. 12, p. 76*).—W. A. D.

used. Scouler willow is, however, an important browse species for range livestock (*25*, *72*).

#### OCCURRENCE AND HABITS

Scouler willow (fig. 55) is frequently a shrub growing about the headwaters of high mountain streams at elevations of 7,000 to 10,000 feet. The highest elevations are reached in the Pacific slope range. At lower elevations along the middle courses of mountain streams and on moist benches, in depressions, and on gentle slopes, this willow more usually appears as a small tree. It attains its greatest size in moist bottom lands on the Pacific slope, where it nearly reaches sea level. Abundant soil moisture and well-drained situations are essential for the best growth. Scouler willow occurs singly and in small groups. In the Pacific slope range it is in many places associated with red alder and bigleaf maple. Unlike other willows Scouler willow is fairly tolerant of shade for a number of years, its height growth not being materially retarded. Ultimately, however, it requires full top light for its best growth. It bears an abundance of seed, and seedlings are numerous but usually are much scattered.

#### LONGEVITY

The extreme age attained by this willow is not known. Trees from 6 to 10 inches in diameter are from 25 to 50 years old. The largest trees are probably from 100 to 125 or more years old.

## FAMILY RELATIONSHIPS AND GENERIC CHARACTERISTICS OF WALNUTS

Walnuts (*Juglans*) are one of the two genera in the United States that represent the aromatic family Juglandaceae. The other representatives are the hickories (*Hicoria*). Juglandaceae, which occur generally in tree form, and rarely as shrubs, are characterized by odd-pinnate leaves and flowers in naked or bracteate catkins, the pistillate flowers being solitary or few-clustered, mostly with a four-toothed calyx and an inferior ovary. The fruit is a nut or, more precisely, a dry modified drupe, either with a firm pulpy covering which does not break off of its own accord (walnuts) or a firm woody covering which at maturity separates into four nearly distinct or partly connected rindlike valves or divisions (hickories). The deciduous, compound leaves occur singly and more or less distant from each other. The North American representatives of this family are commercially important timber trees, and many are also prized for their edible nuts.

Of the 5 species, 1 subspecies, and 3 natural hybrids of walnut indigenous to the United States, only 1 species and a single subspecies occur in the Rocky Mountain region. These are found in the southern Rockies and adjacent Mexican territory. Other representatives of the genus are distributed over many parts of the world.

The walnuts are of ancient origin. Remains of numerous ancient species, once common in Europe but now extinct, have been found in the Cretaceous and Tertiary formations. In the northern Pacific

coast region signs of ancient walnuts have been obtained from the Eocene formation and in the California Sierras from gold-bearing gravel beds. No living representatives are found in these regions now, although two native walnuts occur in California, one near the coast and the other (possibly introduced by the Indians) in the central portion of the State (*20; 49; 50; 51; 52; 76, v. 7; 105*).

A pungent aromatic odor is characteristic of the twigs, leaves, and other green parts of the walnut when bruised. The heartwood is of a rich dark-brown color. Other distinctive characteristics are the triangular leaf scars on the twigs, with three groups of minute dots, and the partitionlike structure of the pith (best seen by slicing a twig longitudinally). The pinnately compound leaves are made up of a single central stem from which grow some 5 to 11 pairs of leaflets, in addition to the terminal leaflet, each appearing like a small simple leaf and usually pointed. By the suppression of one of the terminal pair of leaflets, the number of leaflets may be odd. The flowers appear after the leaves. Staminate or pollen-bearing flowers are long, flexible, pendent catkins, borne singly or in pairs from buds on branches produced the previous season; pistillate flowers, which develop into fruit, have four small petals and are budlike bodies borne in small spikes at the ends of the new green shoots of the season, usually on the same branch as that which bears the staminate flowers. The fruit is a sculptured or rugose nut (spherical in the case of Rocky Mountain walnuts), matured by autumn of the first season. Its firm, more or less pulpy husk breaks up after maturity but with no regular divisions. The heavy fruits are dependent for their distribution upon rodents, which bury many of them for their winter food, and upon flood waters, which often carry them long distances.

### KEY TO ROCKY MOUNTAIN WALNUTS [51]

Leaflets 17–23 (occasionally 13 or 15), lanceolate (mostly narrowly so), about 1 cm broad, long-acuminate, usually falcate, finely serrate or nearly entire; fruit 15–20 mm thick. Stamens about 20; much-branched, round-headed shrub or small tree, ranging from Texas to western Oklahoma and southeastern New Mexico ..... *Juglans rupestris*

Leaflets 9–13 (occasionally 15; rarely 17 or 19), oblong-lanceolate to ovate, about 2 cm broad, acuminate, coarsely serrate; fruit 20–35 mm thick. Stamens about 30–40; medium-sized tree, occasionally 50–60 feet high, with well-defined trunk and narrow crown, ranging from central and southern New Mexico to Arizona ..... *J. rupestris major* (=*J. major*)

## LITTLE WALNUT (JUGLANS RUPESTRIS ENGELM.)

### COMMON NAME AND EARLY HISTORY

*Juglans rupestris* is a species well known within its natural range, but through a misunderstanding of its relationship to nogal (*J. rupestris major*), it has been long considered an eastern form of the latter tree. On account of the smaller stature of *J. rupestris*, its

[51] Key prepared by W. A. Dayton, based largely on the treatments of Britton and Shafer (*19*), Rehder (*63*), Sargent (*79*), and Standley (*83*). It is worthy of note that all four of these authors regard *major* as a species, as does Standardized Plant Names (*4*), and as will Tidestrom in his Flora of Arizona now in course of preparation.

smaller leaves, and especially its diminutive fruit, it seemed desirable to apply to it the name little walnut.[52]

This walnut was first discovered in west-central Texas in 1835 by the Belgian botanist, Jean Luis Berlandier. Sargent (*76, v. 7, p. 126*) cites the existence of a specimen, "No. 2459, Rio de Medina, Texas, June, 1834" in support of this statement. It was first described as a distinct species by Engelmann (*95*) in 1854 under the name *J. rupestris*.[53]

Torrey states that he read a paper about this walnut before the American Scientific Association in August 1851 (see also Dr. Woodhouse's statement (*95, p. 37*) in which he referred to this walnut as *Juglans whippleana*, naming it (at the request of Dr. Bigelow, who sent him the material) in compliment to Lieutenant Whipple, of the Mexican Boundary Commission, but that he afterwards ascertained that Dr. Engelmann had obtained this walnut before him and had already named (but not published) it as *J. rupestris*.

### DISTINGUISHING CHARACTERISTICS

Little walnut is typically a bushy tree, generally 8 to 15 feet high and 6 to 18 inches in diameter, but sometimes 18 to 30 feet in height and correspondingly thicker. The trunk is usually more or less crooked and leaning. The crown is broad and rounded, and the lower branches very often come out close to the ground. The trunk bark is very like that of the nogal. In dry, poor soils the little walnut is often a low shrub with several or many slender stems from 2 to 4 feet high, growing from a common rootstock. The slender reddish-yellow twigs are at first covered with a light-colored short down, which remains during 2 or 3 seasons; finally the twigs become smooth and ashy. The leaves are about 8 to 13 inches long and usually have from 17 to 23 (rarely as few as 13) very narrow, scythe-shaped, long-pointed, leaflets finely toothed, except that the margin of the incurved portion is often entire or nearly so. These leaflets are often practically sessile or else borne on extremely short stalklets (petioles), and range in length roughly from 2 to 3 inches and in width from one half to two thirds of an inch. The main stem (rachis) of the leaf and that of the leaflets is usually slightly hairy, as is also the lower surface of the leaflets along the midvein; otherwise, the leaflets are smooth. The border of the leaflets is often slightly turned under (fig. 56). The fruit, generally borne in great abundance, is spherical or nearly so (sometimes slightly flattened at the basal end) and is covered with a very thin, brownish, minutely rusty-velvety husk. It is from five eighths to three fourths of an inch in diameter, and is reputed to be the smallest known in the genus. The thick-shelled nut, from about one half to five eighths of an inch in diameter, is somewhat pointed at

[52] The name Texas walnut has been adopted for the species in Standardized Plant Names (*4*) and, since this name is suggestive of the principal range of the species, may be considered by many as preferable. Other local names include desert walnut and western walnut.

[53] *J. rupestris* appears to have been first introduced in Europe at the botanic garden of Berlin, Germany, where, according to a note attached to a specimen in Engelmann's herbarium, it was established as early as 1868 (*76, v. 7, p. 126*). Its next introduction into cultivation was in the Arnold Arboretum, near Boston, Mass., where seeds from western Texas were planted in 1879, and it is said to be perfectly hardy in that part of New England where, as a shrubby form, it had matured fruit as early as 1905.

the apex, its body marked with longitudinal, often interrupted or branched grooves; the scanty meat is sweet, with a black-walnut flavor.

### OCCURRENCE AND HABITS

Little walnut is very scattered in its distribution (fig. 57), occurring singly and in small groups on and near the borders of perpetual watercourses and along periodically watered tributary stream beds in desert mountain regions, especially in limestone formations. It inhabits a region of very scanty rainfall and grows in rocky, gravelly soils into which its roots descend to great depths to obtain water. In a few places, widely scattered single trees or small groups, sometimes the only arborescent vegetation, appear along dry washes in rolling hill country. Though the fruit is commonly produced in great abundance every 2 or 3 years, reproduction is rather rare, owing to the fact that the nuts fall on dry ground or among bare rocks where there are few chances of germination. Wide dissemination of the nuts can be accomplished only by flood waters, and the only nuts to germinate are those which have been accidentally covered with soil or have been buried by rodents and left uneaten. Seedling plants of this walnut, like those of the nogal, produce

FIGURE 56.—Foliage and fruit of *Juglans rupestris*. ×½.

a deep-growing taproot during the first 2 or 3 years; the aerial portion of the stem develops very little during that period. The plant is intolerant of shade, growing only in full sunlight.

FIGURE 57.—Geographic distribution of the little walnut (*Juglans rupestris*) (hatched area) and nogal (*J. rupestris major*) (solid black area).

LONGEVITY

Little is known regarding the age limits of this walnut; the age of the largest trees has never been determined and may be anywhere from 85 to 150 years, or possibly much more. Two trees, 6 and 12½ inches in diameter, respectively, were 58 and 114 years old. After

the first 4 or 5 years, if conditions are not too severe, the tree grows rather rapidly.

## NOGAL (JUGLANS RUPESTRIS MAJOR TORR.)

### COMMON NAME AND EARLY HISTORY

*J. rupestris major* is known throughout its range simply as walnut or as nogal.[54] Settlers familiar with the eastern black walnut (*J. nigra*) sometimes distinguish this southwestern species as western walnut. The name Mexican walnut was once arbitrarily applied to this tree under the impression that it was essentially of Mexican origin.

The first authentic record we have of the collection of nogal is that by J. M. Bigelow, botanist of the Mexican Boundary Commission, at Copper Mines (i.e., Santa Rita), Grant County, N.Mex., about 1850, and by S. W. Woodhouse, surgeon-naturalist of the Sitgreaves Expedition down the Zuni and Colorado Rivers in "western New Mexico" (i.e., what is now Arizona) in 1851. In 1854 it was first published under the name *J. rupestris* var. *major* Torr. The publication in the same year of the similar but smaller-fruited *J. rupestris* Engelm. discovered in Texas appears to have led botanists to regard these two distinct forms as geographic phases of one species, and for more than 40 years both were designated as *J. rupestris* Engelm. In 1904, however, Heller (*37*), considering these walnuts specifically distinct, took up for the more western, larger-fruited tree the name *J. major* (Torr.) Heller, based on *J. rupestris major* Torr. In 1908 Britton and Shafer (*19*) adopted this view, as have also Wooton and Standley in 1915 (*104*), Standley in 1920 (*83*), Rehder in 1927 (*63*), Sargent (*79*) in the second edition of his Manual of the Trees of North America, and the American Joint Committee on Horticultural Nomenclature (*4*). After a long and careful study of these two walnuts the writer is convinced that the larger-fruited western one, here designated as *J. rupestris major* Torr.,[55] is a variety of the typically smaller-fruited, more eastern tree (*J. rupestris* Engelm.).

### DISTINGUISHING CHARACTERISTICS

The nogal ordinarily ranges from 15 to 40 feet in height and from 4 to 15 inches in diameter. Exceptionally large trees are 45 to 50 feet in height and 3 to 4 feet in diameter, and the smallest form of this variety is a 3- or 4-foot shrub having several or many stems. The clear length of bole is usually only 6 to 12 feet; the bole above this height divides into a number of large erect or spreading limbs

[54] Nogal is applied by Mexicans to all species of *Juglans*, and hence is indistinctive, without modification, as a specific or varietal name. Clarence A. Reed, in charge of nut culture investigations of the Division of Horticultural Crops and Diseases, Bureau of Plant Industry, suggests adoption of the name Arizona walnut for this walnut.—W. A. D.

[55] According to Elwes and Henry (*30, p. 275*) this walnut was first introduced into cultivation in England in 1894, seeds obtained from the vicinity of Fort Huachuca, Ariz., having been planted at that time in the Royal Gardens at Kew. One tree grown from this seed attained a height in 11 years of about 12 feet. Other single trees planted in England at Tortworth, Colesborne, and Mount Edgcumbe, near Plymouth, reached nearly the same height within from 10 to 12 years.

and smaller branches forming, according to the growing space, a narrow or broad and domelike crown. In some instances the main body of the trunk appears to be greatly suppressed and gives off several spreading trunklike stems from a point at or very near the ground. The bark of young trees and of the branches on old trees is very thin, unbroken, and a light gray that is sometimes almost white. The trunk bark of old trees is from three-fourths to 1 inch thick, grayish brown, and distinctly furrowed and ridged, the surface of the ridges being irregularly divided into thin, firmly attached scales. Twigs of one season's growth are reddish brown. They are more or less downy for two or three seasons, but later be-

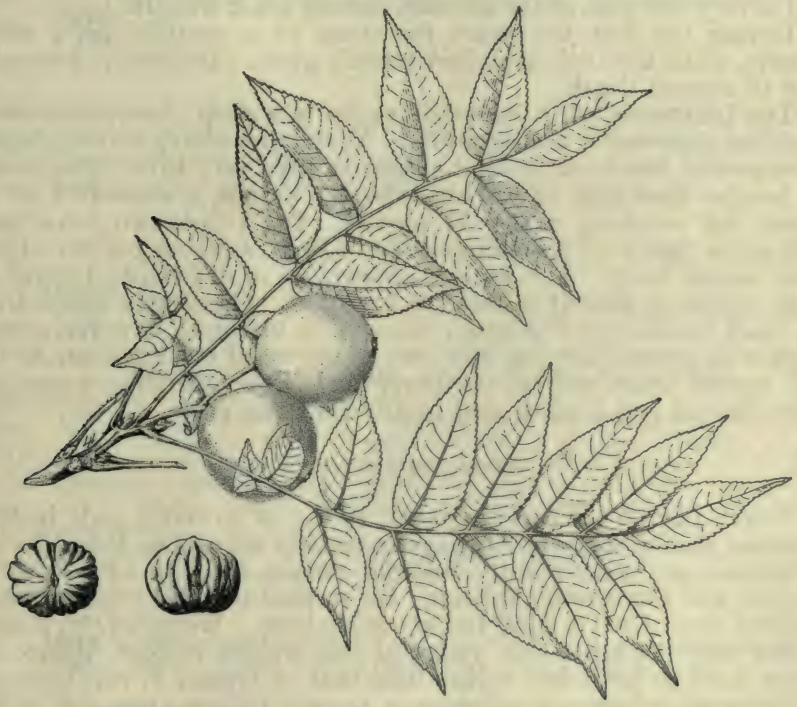

FIGURE 58.—Foliage and fruit of *Juglans rupestris major*. ×½.

come smooth and grayish or nearly white. The terminal mature buds are about one-half inch long, are slightly flattened, and are covered with tawny fine down; the slightly flattened lateral buds are about one eighth of an inch long and are similar in color to the terminal buds.

The compound leaves are 7 to about 14 inches long and are usually made up of 9 to 13 leaflets of a lanceolate or ovate-lanceolate type, all but the terminal or odd leaflet being arranged in opposite or nearly opposite pairs (fig. 58). The main leaf stems are finely hairy, as are, sparingly, the under sides of the leaflets along the midveins; the largest pairs of leaflets range from 3 to 4 inches in length and from 1¼ to 1½ inches in width, and the smallest leaflets are about

2 inches long. The leaflets are thinnish and yellowish green, occasionally somewhat sickle-shaped or falcate, at first scurfy and downy-haired, later hairless (glabrous) on the upper surface, but usually somewhat downy, especially at the midrib, below. The more or less spherical and slightly flattened fruit ranges in diameter from about seven eighths of an inch to 1¼ inches; exceptionally large fruit sometimes is 1½ inches through. The nut is covered with a very thin husk, which is densely coated with light rust-colored down. The thick-shelled, dark-brown or blackish nut is smoother than that of the eastern black walnut, but conspicuously lined with narrow, deep, parallel and branched, wrinklelike furrows. In flavor the kernel is very like that of the common eastern black walnut.

During the first few years the stems of a seedling grow very slowly, while the little-branched taproot grows extensively, descending to a great depth.

The heartwood of *J. rupestris major* is a deep chocolate-brown, and the sapwood is almost white. Young trees have a thick layer of sapwood, but in old trees the layer is often very thin. The wood is heavier than that of any other native walnut, a cubic foot of it when dry weighing nearly 43 pounds. The rich-brown color and attractive figure of the heartwood render it suitable for furniture and cabinet work. The general appearance of the finished wood is very similar to that of eastern black walnut. Occurrence of the tree in small numbers and in rough inaccessible localities, however, probably will prevent any but local use of the wood for lumber. As in the eastern black walnut, the heartwood is very durable in contact with the soil and is often used locally for fence posts.

### OCCURRENCE AND HABITS

Nogal (fig. 57) grows in rough, rocky, or gravelly soils in the bottoms and on the sides of canyons, usually near or on the edges of perpetual or intermittently watered stream beds or adobe-gravel washes and about rocky springs. Its vertical range is from an altitude of about 1,400 to 7,000 feet above sea level. Wooton (*103, p. 49*) states that the altitudinal range of this walnut in New Mexico is from 1,500 to 2,000 feet higher than that of typical *J. rupestris*.

Although where soil moisture is present this tree appears to be indifferent to the quality of the soil, as is shown by its persistent growth even in the poorest rocky, gravelly sites, the largest trees are produced in canyon bottoms where the soil is deep and fertile and moisture is abundant. The largest specimens are found in the central and western parts of the tree's range in New Mexico and Arizona, and the smallest trees in the eastern part of its range.

Nogal grows only as scattered individuals or in groups of a few trees. In general it is associated more or less with *Platanus wrightii*, *Alnus oblongifolia*, cottonwoods, and willows. In southwestern New Mexico it is in some places associated with *Morus microphylla*, the western form of *Quercus muhlenbergii*, *Q. emoryi*, and *Fraxinus pennsylvanica lanceolata*.

This walnut is very intolerant of shade and grows for the most part in the open where direct sunlight or strong diffused light is abundant. Trees growing in the bottoms of narrow canyons where

light is restricted show the influence of this deficiency in their comparatively tall slender trunks, sparse branches, and thin foliage.

Nogal bears fruit abundantly at irregular periods of 2 to 3 years, smaller quantities being produced every other year or so. Notwithstanding the large periodic production of seed, reproduction is relatively sparse, only scattered seedlings coming up where flood waters or some other accidental agency have covered the nuts with soil. In situations where such agencies are rarely if ever helpful, the entire crop of nuts may fail of germination. The germination of the nuts varies greatly from year to year, but the percentage is usually 30 to 50. Squirrels and other rodents consume considerable quantities of the nuts, particularly where the trees grow in wooded canyons at high elevations.

### LONGEVITY

Under the most favorable soil conditions this walnut grows rapidly during the first 25 or 30 years of its life, after which time its increase in height and diameter, and especially in height, is slow. It is long-lived, attaining an age of 300 to 380 or possibly 400 years.

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# FORAGE-CROP FIELD EXPERIMENTS AT WEST POINT, MISS.

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The Bureau of Plant Industry in Cooperation with the Mississippi Agricultural College and Experiment Station

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## INTRODUCTION

The suitability of the limestone soils of the prairie belt of Alabama and Mississippi for alfalfa has been recognized for many years, and the acreage devoted to the crop increased rapidly between 1909 and 1915. About 1919, however, complaints were received to the effect that alfalfa was much less productive and shorter-lived than formerly. The demands for assistance in determining the cause of the so-called "alfalfa failures" culminated in a congressional appropriation which enabled the inauguration in 1925 of experiments to ascertain the causes of the difficulty and to suggest remedial measures. The purpose of this bulletin is to summarize results to date of the field experiments conducted by the Division of Forage Crops and Diseases 5 miles east of West Point, Miss., in cooperation with the Mississippi Agricultural Experiment Station. The experiments have not been of sufficient duration to give conclusive results, but it is quite evident that the decline in yields and in longevity of stands is associated with the lack of available phosphorus, humus deficiency, and poor cultural practices. Tests with other forage crops that appear promising for this section have been carried on more or less incidentally to the alfalfa experiments.

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## DESCRIPTION OF THE SOIL

The prairie limestone belt of Alabama and Mississippi is a crescent-shaped strip of land having an approximate average width of 30 miles and extending from Lee County, Miss., on the north in a southeasterly direction to Butler County, Ala., where it turns east, terminating in Bullock County, Ala. While soft limestone is the predominant underlying rock, the area is interspersed with other geological formations. The leading counties in the prairie limestone belt have a combined area of approximately 6,500,000 acres, of which less than 1,000,000 are derived from limestone and therefore regarded as potential alfalfa lands. The limestone soils of this section have been classed in the Houston, Bell, Sumter, Catalpa, and Eutaw series. Most of the alfalfa has been and is being grown on Houston, Sumter, and Bell clays.

The experiments at West Point are located mainly on the Houston clay, but with a small acreage on Bell and Sumter clays. The

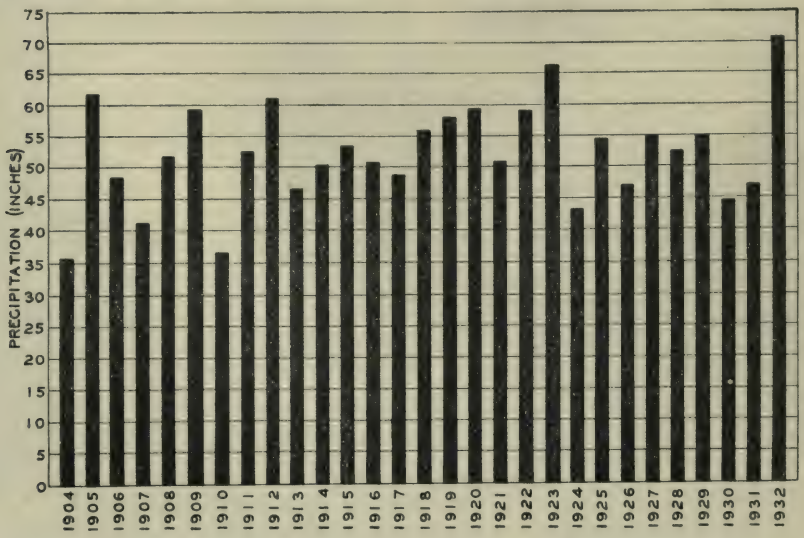


FIGURE 1.—Annual precipitation at Columbus, Miss., 1904–32 (U.S. Weather Bureau records).

Houston and Sumter soils have resulted from the decomposition, in place, of a rather soft shaly limestone that was deposited in the deep waters of the Gulf of Mexico when it covered this section, while Bell clay largely represents wash from adjoining areas of Sumter and Houston clays. These soils are compact, sticky, and tenacious when wet, but upon plowing break readily into a granular structure, due probably to the lime content. In dry periods the soil cracks badly, but with more favorable moisture conditions the cracks fill up readily. The general contour favors good surface drainage but the water table is often relatively high, especially during wet periods.

The practice of continuous cropping mainly to cotton for many years has reduced the organic-matter content and the productivity of these soils, and as they erode readily they should be in sod or some other cover crop during the winter months, when rain is usually most abundant.

## CLIMATE

The average annual precipitation at Columbus, Miss., the nearest weather reporting station, amounted to 54.06 inches during the 33-year period 1888–1920 and 53.34 inches for the years 1925–32. As shown in table 1, the amount and distribution is generally adequate for crop production. The variation in annual precipitation is presented clearly in figure 1. During the summer months the precipitation is often local, while general rains occur during the winter months. Rains are most frequent from the middle of December to late in March. Since evaporation takes place much more slowly in winter, and since the water table is relatively high, it is seldom possible to work the soil during this period. The frost-free period for the past 8 years is given in table 2. The average frost-free period for these years extends from March 24 to November 6. As shown in table 3, the lowest temperatures have occurred in January, but there is little difference in the mean of December, January, and February. July normally is the hottest month. The most abrupt changes occur during February. The prevailing direction of the wind is from the southeast. The most agreeable months are October and November.

TABLE 1.—*Monthly and annual precipitation at Columbus and West Point, Miss., 1888–1932* [1]

| Year | January | February | March | April | May | June | July | August | September | October | November | December | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In.* | *In* | *In.* | *In.* |
| 1921 | 3.33 | 5.04 | 8.44 | 10.18 | 2.45 | 2.38 | 3.95 | 3.96 | 5.47 | 0.58 | 1.99 | 3.23 | 51.00 |
| 1922 | 5.91 | 5.81 | 12.19 | 3.78 | 3.71 | 1.12 | 4.94 | 4.03 | 2.20 | 1.62 | 5.49 | 8.16 | 58.96 |
| 1923 | 5.97 | 6.09 | 6.11 | 6.56 | 6.79 | 2.81 | 6.76 | 6.82 | .50 | 7.35 | 5.01 | 5.63 | 66.40 |
| 1924 | 7.47 | 3.58 | 6.02 | 6.07 | 5.47 | 2.57 | 2.38 | 1.89 | 1.44 | .31 | [2] T | 6.18 | 43.38 |
| 1925 | 11.53 | 3.22 | 4.34 | 1.21 | 4.68 | 2.32 | 6.04 | 1.22 | 4.17 | 8.04 | 4.11 | 3.63 | 54.51 |
| 1926 | 4.78 | 3.15 | 4.29 | 2.66 | 4.62 | 2.16 | 2.81 | 6.73 | .52 | 1.61 | 5.54 | 8.54 | 47.41 |
| 1927 | 2.39 | 7.19 | 8.06 | 1.58 | 7.42 | 5.32 | 2.28 | .98 | 1.23 | 3.33 | 7.07 | 8.22 | 55.07 |
| 1928 | 2.14 | 3.72 | 7.11 | 12.62 | 2.83 | 7.64 | 4.89 | 3.61 | 1.28 | 2.32 | 2.84 | 1.18 | 52.18 |
| 1929 | 5.35 | 4.34 | 10.04 | 3.71 | 4.35 | 3.32 | 1.99 | 1.24 | 3.18 | 3.80 | 10.09 | 3.52 | 54.93 |
| 1930 | 2.80 | 2.83 | 4.97 | 2.04 | 12.41 | .22 | 2.05 | 4.20 | 1.56 | 3.11 | 5.19 | 3.27 | 44.65 |
| 1931 | 2.50 | 4.37 | 4.28 | 1.71 | 3.16 | 2.00 | 5.53 | 4.36 | 1.90 | 2.44 | 5.53 | 9.44 | 47.22 |
| 1932 | 6.81 | 7.92 | 3.76 | 1.44 | 2.36 | 2.01 | 9.15 | 4.05 | 10.55 | 9.40 | 3.64 | 9.65 | 70.74 |
| Mean, 1888–1920 | 5.07 | 5.53 | 6.17 | 5.34 | 3.94 | 4.12 | 4.71 | 4.34 | 3.09 | 2.44 | 4.19 | 5.12 | 54.06 |
| Mean, 1925–32 | 4.79 | 4.59 | 5.86 | 3.37 | 5.23 | 3.12 | 4.34 | 3.30 | 3.05 | 4.26 | 5.50 | 5.93 | 53.34 |

[1] Instruments for recording weather data were installed near West Point, Feb. 10, 1929. All other data are from the records of the nearest U.S. Weather Bureau station, at Columbus, Miss.
[2] T=trace.

TABLE 2.—*Frost-free period at West Point, Miss., 1925–32*

| Year | Killing frost | | Frost-free period (days) | Year | Killing frost | | Frost-free period (days) |
|---|---|---|---|---|---|---|---|
| | Last in spring | First in fall | | | Last in spring | First in fall | |
| 1925 | Mar. 15 | Oct. 20 | 219 | 1929 | Mar. 10 | Nov. 5 | 240 |
| 1926 | Apr. 1 | Oct. 25 | 207 | 1930 | Mar. 31 | Oct. 31 | 214 |
| 1927 | Mar. 23 | Nov. 18 | 240 | 1931 | Mar. 18 | Nov. 7 | 234 |
| 1928 | Apr. 16 | Nov. 11 | 209 | 1932 | Mar. 15 | Nov. 12 | 242 |

TABLE 3.—*Mean maximum, mean minimum, mean, absolute maximum, and absolute minimum temperatures (° F.) at Columbus, Miss., for 30 years*

| Item | January | February | March | April | May | June | July | August | September | October | November | December | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean maximum | 55.0 | 55.0 | 67.0 | 74.7 | 83.6 | 91.1 | 92.3 | 92.2 | 89.1 | 77.8 | 66.2 | 54.9 | 74.9 |
| Mean minimum | 33.5 | 33.2 | 43.4 | 50.4 | 59.3 | 67.1 | 70.2 | 69.9 | 63.5 | 50.6 | 40.0 | 32.9 | 51.2 |
| Mean | 44.2 | 44.1 | 55.2 | 62.6 | 71.4 | 79.1 | 81.2 | 81.0 | 76.3 | 64.2 | 53.1 | 43.9 | 63.0 |
| Absolute maximum | 81.0 | 87.0 | 93.0 | 95.0 | 100.0 | 108.0 | 113.0 | 108.0 | 110.0 | 100.0 | 88.0 | 82.0 | ------ |
| Absolute minimum | −2.0 | 0 | 18.0 | 27.0 | 38.0 | 47.0 | 54.0 | 52.0 | 40.0 | 24.0 | 14.0 | 8.0 | ------ |

## ALFALFA

From available data it appears that alfalfa was first grown in the prairie limestone belt about 1890. According to the United States census, the acreage increased more than 70 percent during the 10-year period 1909–19 (table 4). The advent of the bollweevil turned the attention of farmers to other cash crops as substitutes for cotton, and because of the success with alfalfa much interest developed in it. No data are available as to the acreage in 1915, but it is probable that the peak was reached near that time. Beginning about 1919 many complaints were received of alfalfa failures, and the decline in acreage over the 5-year period 1919–24 amounted to more than 77 percent. The purpose of inaugurating the alfalfa investigations at this station was to determine, if possible, the causes of alfalfa failures and to find remedial measures. The first experimental seeding was made in September 1925, and additional tests have been sown each spring and fall since that time. The results so far indicate that the alfalfa troubles are not due to any single factor, and that the crop may be profitably grown provided certain practices are followed consistently.

TABLE 4.—*Alfalfa acreages in the prairie limestone counties of Mississippi and Alabama* [1]

| Mississippi counties | 1909 | 1919 | 1924 | 1929 | Alabama counties | 1909 | 1919 | 1924 | 1929 |
|---|---|---|---|---|---|---|---|---|---|
| Chickasaw | 328 | 343 | 41 | 99 | Autauga | 5 | 3 | 6 | 3 |
| Clarke | 99 | 8 | 6 | ------ | Bullock | 1 | 147 | ------ | ------ |
| Clay | 1,632 | 2,820 | 23 | 181 | Butler | 2 | ------ | 5 | ------ |
| Jasper | 16 | 11 | 21 | ------ | Dallas | 280 | 89 | 189 | 115 |
| Lee | 745 | 1,905 | 484 | 839 | Greene | 2,496 | 988 | 101 | ------ |
| Lowndes | 1,268 | 2,504 | 585 | 556 | Hale | 506 | 2,577 | 757 | 553 |
| Monroe | 1,183 | 5,154 | 337 | 769 | Lowndes | 474 | 127 | 1 | 20 |
| Newton | 3 | 9 | 6 | 18 | Macon | 3 | ------ | 2 | 6 |
| Noxubee | 1,018 | 898 | 230 | 63 | Marengo | 264 | 1,169 | 597 | 305 |
| Oktibbeha | 294 | 65 | 6 | 38 | Montgomery | 369 | 380 | 500 | 446 |
| Pontotoc | 45 | 330 | 73 | 38 | Perry | 460 | 1,231 | 736 | 618 |
| Prentiss | 44 | 175 | 195 | 229 | Pickens | 445 | 844 | 4 | 22 |
| Rankin | 3 | 5 | ------ | ------ | Sumter | 1,013 | 439 | 90 | 73 |
| Scott | 5 | 6 | 20 | 89 | Wilcox | 142 | 130 | ------ | ------ |
| Union | 3 | 91 | 120 | 26 | | | | | |
| Total | 6,686 | 14,324 | 2,147 | 2,945 | Total | 6,460 | 8,124 | 2,988 | 2,161 |

[1] Figures taken from United States census report.

### VARIETAL TRIALS

The varietal trials of alfalfa conducted during these investigations have included most of the important domestic varieties and strains, as well as several from foreign sources. Depending on ability to survive cold, these alfalfas are placed in three groups as follows: Nonhardy, medium hardy, and hardy. The nonhardy alfalfas, of

which Hairy Peruvian is an example, recover rapidly after cutting, and under favorable conditions produce a greater tonnage of hay than most other sorts. None of the alfalfas in this group is sufficiently cold-resistant to be considered dependable for this section. The medium-hardy group is made up mainly of regional strains of common alfalfa that have developed where rather low winter temperatures are of frequent occurrence, thus resulting in strains that are intermediate in cold resistance. Kansas, Utah, and Dakota Common alfalfas are among the best-known strains in this group. The hardy or variegated alfalfas, of which Grimm is a representative, are cold-resistant but recover slowly after cutting and generally are less productive than alfalfas of the medium-hardy group where winter conditions favor the latter. Both the hardy and medium-hardy alfalfas tend to become dormant with the advent of shorter days and cooler weather.

The results of the varietal trials sown in the fall of 1925 and the spring of 1927 are given in tables 5 and 6, respectively. No fertilizers

FIGURE 2.—Alfalfa variety plots photographed in October 1927. Note the late growth of Arizona Common alfalfa just to the left of the center, as compared with the growth of Turkistan alfalfa in the adjoining plots on the right.

were applied to these plots until the spring of 1929, when those sown in 1925 were top dressed with 16 percent superphosphate, at the rate of 500 pounds per acre. The plots sown in 1927 have not been fertilized. As shown by these tables, the nonhardy alfalfas are less productive, especially after the first year, than the hardier sorts, due to a gradual thinning out. The fact that they continue to grow late in the fall (fig. 2) and often make considerable growth during warm periods in the winter has resulted in the plants becoming infected with Sacketts disease and also injured by cold, with a corresponding loss of stand. Some reduction in stand has also been noted during the summer, especially before the plants become well established.

The hardy alfalfas produced a good quality of hay and survived satisfactorily until the severe winter of 1929–30, when they appeared to suffer more injury than the medium-hardy alfalfas. The average annual yield of air-dry hay of the hardy alfalfas has been almost appreciably less than that of the medium-hardy alfalfas, and about the same as that of the nonhardy alfalfas. However, owing to better

stands, the quality of hay produced by the hardy alfalfas in most cases has been superior to that obtained from the nonhardy sorts. Turkistan alfalfa, which is decidedly cold-resistant, has proved to be one of the most unsatisfactory varieties, both as regards productivity and survival. The rapid deterioration in stands of this alfalfa seems to be due in part to its susceptibility to leaf-spot disease under humid conditions. Since the hardy alfalfas yield less than the medium-hardy alfalfas, and since they have not shown a greater tendency to survive, they are not recommended for this section. From the data available it is evident that seed of common alfalfa from Kansas and Utah is as satisfactory as any alfalfa for the prairie limestone belt. Argentine alfalfa, seed of which is sometimes imported in considerable quantity, has given about as good yields as Kansas and Utah alfalfas.

TABLE 5.—*Annual and average yields of air-dry hay and estimated stand of several varieties and strains of alfalfa sown in the fall of 1925*

| Variety or strain | Acre yield | | | | | Estimated stand in— | |
|---|---|---|---|---|---|---|---|
| | 1926 [1] | 1927 | 1928 | 1929 | Average | Fall of 1929 | Spring of 1930 |
| Nonhardy group: | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Percent* | *Percent* |
| Hairy Peruvian | 1.20 | 3.61 | 2.08 | 3.21 | 2.52 | 30 | 4 |
| Smooth Peruvian | 1.13 | 3.44 | 1.94 | 3.26 | 2.44 | 44 | 7 |
| Arizona Common | 1.13 | 3.36 | 1.78 | 2.80 | 2.27 | 37 | 9 |
| Spanish | 1.06 | 2.67 | 1.59 | 2.57 | 1.97 | 54 | 4 |
| Italian | 1.20 | 3.84 | 2.13 | 3.60 | 2.69 | 60 | 13 |
| South African | 1.19 | 3.34 | 2.17 | 2.99 | 2.42 | 68 | 15 |
| Medium-hardy group: | | | | | | | |
| Kansas Common | 1.78 | 4.56 | 2.63 | 3.62 | 3.15 | 70 | 34 |
| Utah Common | 1.48 | 4.55 | 2.60 | 3.40 | 3.01 | 70 | 42 |
| Argentine (Chubut) | 1.51 | 4.39 | 2.71 | 3.65 | 3.06 | 65 | 37 |
| Argentine | 1.46 | 4.53 | 2.56 | 3.86 | 3.10 | 70 | 35 |
| Dakota Common | 1.23 | 3.47 | 2.17 | 3.33 | 2.55 | 79 | 20 |
| Lebeau | 1.09 | 3.57 | 2.37 | 3.09 | 2.53 | 70 | 10 |
| Hardy group: | | | | | | | |
| Grimm | 1.03 | 2.77 | 1.62 | 2.96 | 2.09 | 80 | 8 |
| Ontario Variegated | 1.00 | 2.85 | 1.66 | 3.03 | 2.13 | 72 | 15 |
| Cossack | .99 | 3.31 | 2.21 | 3.03 | 2.38 | 72 | 10 |
| Hardigan | .60 | 2.93 | 2.06 | 2.84 | 2.11 | 73 | 68 |
| Turkistan | 1.06 | 2.11 | 1.72 | 1.92 | 1.70 | 17 | 3 |

[1] First cutting not included.

TABLE 6.—*Annual and average yields of air-dry hay and estimated stand of several varieties and strains of alfalfa sown in the spring of 1927*

| Variety or strain | Acre yield | | | | | | Estimated stand in fall of 1931 |
|---|---|---|---|---|---|---|---|
| | 1927 | 1928 [1] | 1929 | 1930 [2] | 1931 | Average | |
| Nonhardy group: | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Percent* |
| Hairy Peruvian | 1.83 | 1.44 | 3.02 | 0.71 | 2.21 | 1.85 | 15 |
| Arizona Common | 1.69 | 1.30 | 2.94 | .79 | 2.35 | 1.81 | 27 |
| Spanish | .84 | .95 | 2.33 | .55 | 2.07 | 1.35 | 30 |
| Do | .87 | .96 | 2.51 | .57 | 2.23 | 1.43 | 30 |
| Italian | 1.14 | 1.43 | 3.15 | .77 | 2.96 | 1.89 | 50 |
| Medium-hardy group: | | | | | | | |
| Kansas Common | 1.50 | 1.75 | 3.22 | 1.04 | 3.53 | 2.21 | 65 |
| Utah Common | 1.24 | 1.32 | 2.92 | .95 | 2.96 | 1.88 | 57 |
| Do | 1.37 | 1.43 | 2.95 | .94 | 2.86 | 1.91 | 60 |
| Dakota Common | 1.69 | 1.86 | 3.77 | .98 | 3.71 | 2.40 | 55 |
| Do | 1.06 | 1.51 | 3.17 | .94 | 3.42 | 2.02 | 52 |
| Dakota No. 12 | 1.30 | 1.47 | 3.07 | .84 | 3.18 | 1.97 | 58 |
| Lebeau | 1.22 | 1.45 | 3.05 | .88 | 3.07 | 1.93 | 63 |
| Hardy group: | | | | | | | |
| Grimm | 1.07 | 1.16 | 2.90 | .72 | 2.78 | 1.73 | 42 |
| Do | 1.02 | 1.24 | 2.91 | .66 | 2.68 | 1.70 | 37 |
| Ontario Variegated | 1.19 | 1.47 | 2.69 | .85 | 3.09 | 1.86 | 25 |
| Cossack | 1.24 | 1.63 | 3.45 | .83 | 3.22 | 2.07 | 33 |
| Turkistan | .87 | 1.16 | 2.39 | .81 | 2.48 | 1.54 | 2 |

[1] Third cutting not included.

[2] Low yields due to severe drought.

### FERTILIZER EXPERIMENTS

In preliminary fertilizer tests the only appreciable increase in growth of alfalfa resulted on plots receiving stable manure or phosphorus (fig 3). Nitrogen and potash alone did not affect the growth materially, and when combined with phosphorus to make a complete fertilizer, increased the yield very little, if any, over phosphorus alone. This being the case, later experiments were designed to determine (1) the comparative value of manure and the three common sources of phosphorus—superphosphate, basic slag, and raw rock—alone and

FIGURE 3.—Harvesting a second cutting of alfalfa on the fertilizer plots.

in various combinations, (2) the most economical rates of application, and (3) the time and frequency of applying for best results.

The yields of hay from the fertilizer tests sown in 1926 and 1928 are given in tables 7 and 8, respectively. The basic slag used in the 1926 seeding was known as Duplex basic slag phosphate, the analysis tag showing 16 percent of available phosphoric acid. As this product is no longer manufactured, ground open-hearth basic slag was used in the later tests, applications being increased to correspond to 16 percent superphosphate.

TABLE 7.—*Annual and average acre yields of air-dry hay from fertilized plots of alfalfa, sown in the spring of 1926*

| Fertilizer and rate of application | 1926 | 1927 | 1928 | 1929 | Average |
|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| No fertilizer | 0. 23 | 1. 97 | 1. 13 | 0. 79 | 1. 03 |
| 20 tons stable manure | . 79 | 4. 53 | 3. 79 | 3. 76 | 3. 22 |
| 10 tons stable manure, 500 pounds superphosphate | . 65 | 4. 54 | 4. 39 | 3. 55 | 3. 28 |
| 500 pounds superphosphate | . 37 | 3. 46 | 3. 02 | 1. 96 | 2. 20 |
| 250 pounds superphosphate | . 32 | 3. 24 | 2. 61 | 1. 84 | 2. 00 |
| 2 tons ground limestone | . 40 | 2. 63 | 1. 62 | 1. 29 | 1. 49 |
| 1,000 pounds basic slag | . 40 | 4. 02 | 2. 85 | 2. 25 | 2. 38 |

TABLE 8.—*Annual and average acre yields of air-dry alfalfa hay comparing the effect of manure and different sources of phosphorus alone and in combination, sown in the spring of 1928*

| Fertilizer and rate of application | 1928 | 1929 | 1930 | 1931 | 1932 | Average |
|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| No fertilizer | 0.90 | 1.89 | 0.99 | 2.16 | 2.23 | 1.63 |
| 20 tons stable manure | 2.09 | 3.20 | 1.72 | 3.55 | 3.19 | 2.75 |
| 20 tons stable manure, 500 pounds superphosphate (16 percent) | 2.03 | 3.25 | 1.91 | 3.95 | 3.78 | 2.98 |
| 20 tons stable manure, 250 pounds superphosphate | 1.99 | 3.66 | 1.98 | 3.84 | 3.50 | 2.99 |
| 20 tons stable manure, 250 pounds superphosphate annually | 2.19 | 3.65 | 1.92 | 4.07 | 3.72 | 3.11 |
| 20 tons stable manure, 500 pounds basic slag | 2.19 | 3.84 | 1.89 | 4.21 | 3.77 | 3.18 |
| 20 tons stable manure, 1,000 pounds raw rock phosphate | 2.07 | 3.62 | 1.82 | 3.71 | 3.27 | 2.90 |
| 10 tons stable manure | 1.91 | 2.87 | 1.36 | 2.85 | 2.76 | 2.35 |
| 10 tons stable manure, 500 pounds superphosphate | 1.93 | 3.26 | 1.48 | 3.69 | 3.30 | 2.73 |
| 10 tons stable manure, 250 pounds superphosphate | 1.79 | 2.99 | 1.32 | 3.26 | 3.17 | 2.51 |
| 10 tons stable manure, 250 pounds superphosphate annually | 1.71 | 3.18 | 1.32 | 3.78 | 3.40 | 2.68 |
| 10 tons stable manure, 500 pounds basic slag | 1.75 | 3.16 | 1.34 | 3.37 | 3.20 | 2.56 |
| 10 tons stable manure, 1,000 pounds raw rock phosphate | 1.44 | 2.60 | 1.15 | 2.59 | 2.72 | 2.10 |
| 1,000 pounds superphosphate | 1.29 | 2.81 | 1.15 | 2.68 | 2.78 | 2.14 |
| 1,000 pounds basic slag | .83 | 2.60 | 1.09 | 2.50 | 2.70 | 1.94 |
| 1,000 pounds raw rock phosphate | .77 | 1.64 | .88 | 1.89 | 1.95 | 1.43 |
| 500 pounds superphosphate (biennially) | 1.05 | 1.94 | 1.17 | 3.09 | 2.79 | 2.01 |
| 500 pounds basic slag (biennially) | .63 | 1.44 | .92 | 2.68 | 2.46 | 1.63 |
| 250 pounds superphosphate (annually) | 1.17 | 2.37 | 1.44 | 3.29 | 2.85 | 2.22 |
| 250 pounds basic slag (annually) | .89 | 1.83 | 1.21 | 2.96 | 2.83 | 1.94 |

The applications of phosphates alone on the 1928 seedings were so planned that at the end of 4 years each plot would have received the equivalent of 1,000 pounds of superphosphate with the exception of the raw rock, which was applied in the beginning at the rate of 1,000 pounds per acre, no analysis of the available phosphoric acid being at hand. The low yields in 1928 from the spring seeding of that year are due to the fact that the plants had not had an opportunity to become well established, and the low yields in 1930 are due to a drought so severe that little hay was obtained from the second cutting. In both of these tests the highest average yields were obtained from the plot receiving stable manure in combination with 16 percent superphosphate or basic slag, though the combination usually has had only a slight advantage over the same amount of manure applied alone.

Basic slag and 16 percent superphosphate alone increased the yields to some extent, but the raw rock phosphate apparently had noe ffect. Annual applications of 16 percent superphosphate at the rate of 250 pounds per acre seemed to have some advantage over double this amount applied every other year, though the increase may not always justify the additional labor involved. That the beneficial effects from fertilizer applications carry over to subsequent crops is shown by the yields of corn given in the following tabulation. In this test the highest yields of corn were obtained from the plots that produced the greatest tonnage of alfalfa.

| Acre rates and kind of fertilizer applied to alfalfa: | *Yield per acre (bushels)* |
|---|---|
| No fertilizer | 29.98 |
| 20 tons stable manure | 43.42 |
| 10 tons stable manure and 500 pounds superphosphate | 45.32 |
| 500 pounds superphosphate | 38.69 |
| 250 pounds superphosphate | 38.07 |
| 2 tons ground limestone | 29.76 |
| 1,000 pounds basic slag | 35.99 |

### GREEN-MANURING EXPERIMENT

Since previous tests had shown the beneficial effects on alfalfa from liberal applications of barnyard manure, an experiment was inaugurated to determine whether green manures would serve a similar purpose. Table 9 gives the yields of alfalfa obtained after plowing under soybeans, velvetbeans, and cowpeas. Unfortunately, this test did not include an untreated check plot, but by comparing the yields obtained from the checks in table 8, covering the same period, it is quite evident that the green manures were responsible for an appreciable increase in production of alfalfa. The differences in yields following the various legumes are not significant.

TABLE 9.—*Annual and average acre yields of air-dry alfalfa hay, showing effects of annual legumes turned under as green manure before seeding to alfalfa*

[Sown in September 1927]

| Crop used as green manure | 1928 | 1929 | 1930 | 1931 | 1932 | Average |
|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| Biloxi soybeans | 2.27 | 4.03 | 1.12 | 4.00 | 3.56 | 3.00 |
| Laredo soybeans | 2.22 | 3.98 | 1.42 | 3.70 | 3.18 | 2.90 |
| Otootan soybeans | 2.17 | 4.00 | 1.23 | 3.65 | 3.38 | 2.89 |
| Velvetbeans | 2.37 | 4.12 | 1.33 | 3.67 | 3.30 | 2.96 |
| Brabham cowpeas [1] | 2.75 | 4.21 | 1.48 | 3.97 | 3.39 | 3.16 |

[1] The plots on which Brabham cowpeas were used as green manure had an application of 500 pounds of superphosphate per acre at time of seeding.

### DATE OF SEEDING

For the purpose of obtaining specific information on the best seeding date, alfalfa has been sown at various times in the fall and spring each year since the experimental work was started in 1925. These tests have shown rather conclusively that with favorable moisture conditions fall seedings are preferable, as weeds are less troublesome and better yields are obtained the following season than when seeding is delayed until early spring. Unfortunately, the moisture is often so deficient in the fall that it becomes necessary to postpone seeding until spring. Fall seedings may be made any time between September 1 and October 15, when sufficient moisture is available to insure germination of the seeds. Soybeans leave the land in excellent condition for fall seedings, and the roots and stubble tend to protect the young alfalfa and to check erosion. Short-season varieties of soybeans will mature seed in time to permit fall seeding of alfalfa, but the late-maturing varieties should be harvested for hay when the crop is to be followed by fall-sown alfalfa. Land on which soybeans have been grown is easily prepared for alfalfa by disking and harrowing. Cotton picking is seldom completed early enough to permit proper preparation of the land for fall seeding. Unfortunately, the moisture is often so deficient in the fall that it becomes necessary to postpone seeding until spring. Cotton land that has been well cultivated is usually easily prepared for spring seedings, which should be made as soon after March 1 as the land can be worked. Weeds are usually a more serious factor in spring seedings, especially in late spring seedings, as they frequently choke out many of the young plants before they have become established.

### STAGE OF CUTTING

A test was outlined to determine the effect of cutting at various stages of growth upon the yields and survival of alfalfa, the results being given in table 10. Under humid conditions the alfalfa blooms so sparingly that it is frequently difficult to determine the stage of growth by the percentage of bloom. In this experiment, therefore, when the conditions were unfavorable to the development of flowers, the alfalfa has been cut at intervals which are believed to approximate the stages indicated in the table and varying from 3 weeks for the bud to 8 weeks for the seed-pod stage. The relatively thin stands of all the plots, as shown in the table, are due to the fact that they were 6 years old when these estimates were made and the only fertilizer treatment had been the application of 500 pounds of 16 percent superphosphate in the spring of 1929. The data show conclusively that cutting at an early stage has resulted in a reduced tonnage and rapid deterioration of stands. Cuttings made after the seed pods have formed, while not noticeably injurious to the stand, have resulted in a poor quality of hay and have been conducive to the growth of annual weeds. The long period between cuttings has given many of the weeds an opportunity to mature seed and thereby to increase in number from year to year. The less frequent cuttings also have tended to encourage Johnson grass. From the results of this test it appears that the most desirable stage of cutting alfalfa is when the plants are one half in bloom to full bloom, or, in the absence of flowers, when the basal shoots are well started.

TABLE 10.—*Average and annual acre yields of air-dry hay and estimated stand of alfalfa cut at various stages of growth*

| Stage of cutting | 1927 | 1928 | 1929 | 1930 | 1931 | Average | Stand in fall of 1931 |
|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Percent* |
| Bud stage | 1.89 | 1.63 | 1.61 | 0.58 | 1.26 | 1.39 | 23 |
| ⅛o bloom | 2.09 | 1.87 | 2.29 | .92 | 1.85 | 1.80 | 43 |
| ¼ bloom | 2.28 | 1.91 | 2.56 | 1.33 | 2.11 | 2.04 | 45 |
| Full bloom | 2.59 | 1.96 | 2.60 | 1.20 | 1.97 | 2.06 | 38 |
| Seed pods formed | 1.91 | 2.04 | 2.39 | 1.01 | 1.95 | 1.86 | 68 |
| First cutting, bud stage; other cuttings, full bloom | 2.74 | 1.82 | 2.76 | 1.03 | 1.68 | 2.01 | 23 |

### CULTIVATION

A test to determine the effect of cultivation on yields and survival of alfalfa has been in progress 5 years. These plots were not fertilized until 1929, when they received 16 percent superphosphate at the rate of 500 pounds per acre. As originally planned, this experiment included an early spring cultivation, but due to the frequent rains at this time of the year and the tendency of the soil to dry slowly, it has been necessary to delay cultivation until after the first cutting. As shown in table 11, cultivation has not increased the yields of hay, though weeds have been less abundant in the cultivated plots, especially in the late cuttings. None of the treatments appears to have injured the alfalfa. The most desirable implement for cultivating alfalfa is the so-called alfalfa harrow, which is a modified form of the spring-tooth harrow. The disk harrow has a tendency to split the

crowns and thus open the way for the entrance of various diseases. Cultivation of alfalfa is not advised until the plants are at least 1 year old.

TABLE 11.—*Annual and average acre yields of air-dry hay and estimated stand of uncultivated and cultivated plots of alfalfa*

| Treatment | 1927 | 1928 | 1929 | 1930 | 1931 | Average | Stand in fall of 1931 |
|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Percent* |
| Uncultivated | 2.85 | 1.69 | 2.71 | 0.77 | 1.94 | 1.99 | 38 |
| Disked after first cutting | 2.64 | 1.61 | 2.56 | .77 | 1.98 | 1.91 | 43 |
| Spring-tooth harrow after first cutting | 2.65 | 1.52 | 2.64 | .77 | 2.10 | 1.94 | 53 |
| Disked after each cutting | 2.64 | 1.21 | 2.59 | .72 | 2.44 | 1.92 | 58 |
| Spring-tooth harrow after each cutting | 2.69 | 1.27 | 2.52 | .73 | 2.66 | 1.98 | 58 |

## PROTEIN CONTENT OF ALFALFA VARIETIES

The protein content of each cutting of several varieties of alfalfa was determined during the season of 1929, the results being given in table 12. All alfalfas were harvested on the same date, when Kansas and Utah alfalfas had reached the stage of growth generally recommended for cutting. The slightly lower protein content of the rapid-growing alfalfas, such as Spanish, Arizona Common, and Hairy Peruvian, is doubtless due to the fact that they were more mature when harvested. The protein content of Grimm and Cossack alfalfa was somewhat higher than that of other alfalfas, probably because they recovered slowly after cutting and were therefore less mature.

TABLE 12.—*Protein content on a dry basis of different cuttings of alfalfa varieties in 1929* [1]

| Variety or strain | First cutting | Second cutting | Third cutting | Fourth cutting | Average |
|---|---|---|---|---|---|
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Italian | 20.28 | 19.46 | 19.90 | 21.97 | 20.40 |
| Spanish | 21.38 | 18.68 | 20.27 | 19.35 | 19.92 |
| Lebeau | 20.65 | 19.49 | 21.96 | 22.69 | 21.20 |
| Utah Common | 21.74 | 19.90 | 21.31 | 23.63 | 21.65 |
| Arizona Common | 18.62 | 18.45 | 19.99 | 22.42 | 19.87 |
| Turkistan | 19.52 | 21.01 | 20.66 | 22.62 | 20.95 |
| Ontario Variegated | 22.13 | 20.36 | 20.71 | 23.00 | 21.55 |
| Kansas Common | 20.25 | 19.19 | 20.85 | 22.83 | 20.78 |
| Hairy Peruvian | 19.06 | 18.47 | 19.59 | 20.91 | 19.51 |
| Dakota Common | 20.51 | 19.55 | 21.81 | 22.02 | 20.97 |
| Grimm | 22.46 | 20.70 | 22.87 | 25.99 | 23.01 |
| Cossack | 21.17 | 20.82 | 22.23 | 25.53 | 22.44 |
| Dakota No. 12 | 21.71 | 20.30 | 22.39 | 24.31 | 22.18 |

[1] Analyses made by W. F. Hand, Mississippi Agricultural Experiment Station.

## DISEASES

Bacterial wilt (*Phytomonas insidiosum* (McC.) Bergey et al.) has not been observed in the experimental plots near West Point, but has been found in fields near Muldon and Shannon, Miss., though apparently not very serious. Fusarium wilt (*Fusarium oxysporum medicaginis* Weimer) was discovered in the experimental plots in 1926, but the disease does not appear to have increased rapidly, nor has it been particularly destructive. Crown wart (*Urophlyctis alfalfae* (Lagh.) Magn.) has been observed in several fields, but apparently it is not

doing much damage. The presence of the disease is indicated by the warty growth around the crown of the alfalfa plant in early spring, usually disappearing by the middle of June. Where the disease is abundant it is advisable to rotate with other crops.

#### INSECTS

Of the several insects that injure alfalfa, the damage caused by the 3-cornered leaf hopper (*Stictocephala festina* Say) is generally most noticeable, being in evidence as a yellowing of the tops which results from a girdling of the stems by the insects. This type of damage is usually more prevalent in dry seasons. Measurement of girdled and ungirdled stems showed a difference in height of 20 percent in favor of the latter. As a rule, damage done by the insect is not sufficient to justify control measures.

FIGURE 4.—Otootan soybeans in 3½-foot rows.

## OTHER CROPS TESTED

#### SOYBEANS

The work with soybeans has included (1) comparative trials of some of the more common varieties for hay and seed production, (2) testing new introductions or selections, (3) inoculation and fertilizer experiments. Table 13 presents a 6-year summary of the air-dry hay yields of several varieties and selections sown broadcast and in rows and of seed yields from row plantings.

The Otootan (figs. 4 and 5), Laredo, Biloxi, and Mammoth Yellow are the varieties most commonly grown in this section. Otootan and Laredo are much finer stemmed than Biloxi or Mammoth Yellow and are therefore better suited for hay production. Laredo is grown more generally than Otootan, as it produces more seed, matures about 1 month earlier, and the seed is cheaper. Otootan yields somewhat more hay than Laredo, but usually it is not ready for harvest until early in October, when difficulty is often encountered in curing, due to the short days and less favorable weather. Mammoth Yellow and Biloxi are erect and so coarse that considerable

loss results in feeding the hay. They are therefore used for grazing or soil improvement, either sown alone or in combination with corn or sorghum. Mammoth Yellow is ready for grazing or hay considerably earlier than Biloxi.

FIGURE 5.—Otootan soybeans sown broadcast for hay.

TABLE 13.—*Average acre hay and seed yield of varieties and selections of soybeans*

| Variety | Air-dry hay | | Seed from 3.3-foot rows | Variety | Air-dry hay | | Seed from 3.3-foot rows |
|---|---|---|---|---|---|---|---|
| | Seeded broadcast | Seeded in 3.3-foot rows | | | Seeded broadcast | Seeded in 3.3-foot rows | |
| | *Tons* | *Tons* | *Bushels* | | *Tons* | *Tons* | *Bushels* |
| Otootan [1] | 2.81 | 3.03 | 11.78 | F.P.I. no. 60274 [1] | 1.29 | 1.51 | 11.56 |
| Laredo [2] | 2.32 | 2.75 | 13.93 | F.P.I. no. 60275 [1] | ------ | ------ | 12.78 |
| Mammoth Yellow [1] | 1.66 | 2.39 | 13.90 | F.P.I. no. 60299 [1] | ------ | ------ | 12.83 |
| George Washington [1] | 1.81 | ------ | 11.53 | F.P.I. no. 62838 [1] | 2.74 | 1.47 | 13.70 |
| Pine Dell Perfection [2] | 1.68 | ------ | 11.43 | F.P.I. no. 62842 [1] | ------ | 1.42 | 11.13 |
| Biloxi [2] | 1.97 | 1.45 | 11.34 | F.P.I. no. 62846 [2] | ------ | ------ | 10.17 |
| Selection no. 04886 [1] | 2.13 | 1.65 | 13.90 | F.P.I. no. 71595 [3] | ------ | 1.70 | 11.64 |
| Selection no. 04888–A [1] | 1.80 | 1.14 | 12.47 | F.P.I. no. 71605 [3] | ------ | 1.53 | 15.15 |
| F.P.I. selection no. 36906–A–7–11 [1] | 1.77 | 1.22 | 15.13 | F.P.I. no. 71638 [3] | ------ | ------ | 16.82 |
| F.P.I. selection no. 60175–F [1] | 1.76 | 1.24 | 15.05 | F.P.I. no. 71664 [3] | ------ | 1.68 | 18.13 |
| F.P.I. no. 60247 [2] | 2.34 | 1.78 | 11.74 | F.P.I. no. 71792 [3] | ------ | ------ | 18.70 |
| | | | | Selection no. 05458–1 [1] | 1.63 | 1.57 | 11.19 |

[1] 5-year average. [2] 6-year average. [3] 4-year average.

The highest-yielding varieties of soybeans have not produced quite as much hay as the best alfalfas, and the cost of seeding broadcast or in close drills has been about the same. And since alfalfa produces satisfactorily for 4 years it is a more economical hay crop. Some of the limestone soils are not suited to alfalfa but do grow soybeans satisfactorily, giving a greater tonnage of hay of a higher feeding value than is obtained from three cuttings of Johnson grass, which is the crop commonly grown on such lands. In this section the best yields of hay and seed have been obtained from plantings made during April and May. June plantings generally are less produc-

tive, and July plantings are apt to be injured by cold weather before maturing. Plantings made in March, while usually successful, mature little if any sooner, nor are they any more productive than those made in April and May. They require more cultivation to keep the weeds, especially Johnson grass, under control.

Inoculation tests conducted during the season of 1926 showed no advantage from the use of cultures either in yield of hay or in number of nodules. Applications of 16 percent superphosphate at the rate of 300 pounds per acre in 1926 did not increase the yields of hay. However, this test was conducted on very productive soil where the air-dry hay from both fertilized and unfertilized plots amounted to more than 4 tons per acre.

Insects that at times cause considerable damage to soybeans are the corn earworm, the velvetbean caterpillar, the southern grass worm, grasshoppers, and blister beetles.

The only disease of any consequence has been the stem rot (*Sclerotium rolfsii* Sacc.), and no serious damage has been done by it, although the increase in the number of plants affected by the disease is noticeable where the soybeans have been grown continuously for a period of years. The disease may be controlled by practicing systematic crop rotation.

### SOYBEANS AND CORN

Soybeans have been planted in various combinations with corn, the total yield per acre in each case being about the same. In all of the tests the yields of corn have been decreased by planting with soybeans, although the mixture is more valuable for feeding because of the high protein content of the soybeans. Moreover, the soybeans have a beneficial effect on the soil. Comparative yields of soybean hay and the grain yields of corn when grown alone and in combination are given in table 14. The production of corn stover has not been taken into account in these tests, but a considerable amount of valuable roughage is available from this source.

TABLE 14.—*Average acre yields of soybean hay and corn grown alone and in combination in rows 3.3 feet apart*

| Method of planting | Air-dry soybean hay | Corn | Method of planting | Air-dry soybean hay | Corn |
|---|---|---|---|---|---|
| | *Tons* | *Bu.* | | *Tons* | *Bu.* |
| Otootan soybeans alone [1] | 2.25 | ------ | Corn alone [1] | ------ | 23.50 |
| Otootan soybeans and corn [1] | 1.36 | 16.68 | Otootan soybeans and corn in alternate rows [2] | 1.12 | 14.33 |
| Laredo soybeans alone [1] | 2.47 | ------ | Laredo soybeans and corn in alternate rows [2] | 1.06 | 13.39 |
| Laredo soybeans and corn [1] | 1.37 | 13.19 | Biloxi soybeans and corn in alternate rows [3] | .41 | 16.55 |
| Biloxi soybeans alone [2] | 1.63 | ------ | Mammoth Yellow soybeans alone [3] | .30 | 12.74 |
| Biloxi soybeans and corn [2] | .79 | 17.95 | | | |
| Mammoth Yellow soybeans alone [3] | 1.28 | ------ | | | |
| Mammoth Yellow soybeans and corn [3] | .48 | 12.98 | | | |

[1] 6-year average. [2] 5-year average. [3] 4-year average.

### SORGHUMS

Sorghums are grown for hay, fodder, silage, and grain production and to a much less extent for the production of sirup. Grain sorghums do not appear promising for this section because of frequent injury by the sorghum midge and the favorable moisture conditions which usually insure better yields of grain from corn. During the 6 years of the test, grain sorghums produced sufficient seed for replanting in only one season, 1930. The low yields were due largely to the sorghum midge, which is most destructive during rainy seasons. Schrock and

FIGURE 6.—Honey sorgo.

Darso are the most promising varieties of grain sorghums. In forage production the sorgos, or sweet sorghums, have done well, the better strains producing a greater tonnage than corn. Honey sorgo (fig. 6), a late variety, has given the heaviest yields, but some of the earlier varieties, such as Sumac and Red Amber, while less productive, are easier to harvest. The Gooseneck sorgo is objectionable because of its tendency to lodge. Forage yields obtained from the varieties under test are shown in table 15.

TABLE 15.—*Annual and average acre yields of green and air-dry forage of several varieties of grain sorghum and of sorgo*

| Variety | Green forage | | | | | | | | Air-dry forage | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Average | | | | | | | | Average | |
| | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1929–31 | 1926–31 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1929–31 | 1926–31 |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| Schrock | 5.78 | 7.59 | 4.06 | 6.01 | 9.03 | 12.54 | 9.19 | 7.50 | 2.69 | 3.21 | 1.91 | 2.70 | 2.78 | 3.39 | 2.96 | 2.78 |
| Sagrain | 6.47 | 7.36 | 4.35 | 5.48 | 9.35 | 11.73 | 8.85 | 7.46 | 2.84 | 3.21 | 1.97 | 2.52 | 2.98 | 4.09 | 3.20 | 2.94 |
| Darso | | | | 5.38 | 5.20 | 10.73 | 7.10 | | | | | 2.57 | 2.53 | 3.33 | 2.81 | |
| Hegari | | | | 5.70 | 15.56 | 14.10 | 11.79 | | | | | 2.45 | 4.68 | 6.35 | 4.49 | |
| Straightneck milo | | | | 5.78 | 8.11 | 13.01 | 8.97 | | | | | 2.55 | 2.52 | 4.91 | 3.33 | |
| Blackhull kafir | | | | 5.07 | 9.20 | 11.56 | 8.61 | | | | | 2.17 | 2.55 | 4.61 | 3.11 | |
| Spur feterita | | | | 4.47 | 7.30 | 9.74 | 7.17 | | | | | 1.88 | 1.73 | 3.68 | 2.43 | |
| Grohoma | | | | | | 10.98 | | | | | | | | 3.00 | | |
| Red Amber | | | | | 13.19 | 16.69 | | | | | | | 3.79 | 4.78 | | |
| African millet | | | | 8.20 | 16.23 | 17.64 | 14.02 | | | | | 3.69 | 7.01 | 8.00 | 6.23 | |
| Sumac | 7.89 | 8.20 | 5.65 | 8.38 | 12.65 | 19.21 | 13.41 | 10.33 | 3.83 | 3.33 | 2.99 | 4.01 | 3.27 | 6.79 | 4.69 | 4.04 |
| Kansas Orange | 8.70 | 8.65 | 5.46 | 10.47 | 12.66 | 19.44 | 14.19 | 10.90 | 4.64 | 4.04 | 2.85 | 4.60 | 5.18 | 8.95 | 6.24 | 5.04 |
| Atlas | | | | 8.96 | 15.25 | 19.58 | 14.60 | | | | | 4.44 | 6.59 | 9.20 | 6.74 | |
| Saccaline | | | | 10.86 | 17.03 | 16.85 | 14.91 | | | | | 5.29 | 7.24 | 9.50 | 7.34 | |
| Honey | 15.87 | 13.68 | 8.67 | 11.48 | 23.38 | 32.42 | 22.43 | 17.58 | 7.28 | 6.17 | 5.96 | 6.10 | 8.93 | 16.65 | 10.56 | 8.52 |
| Gooseneck | | | | | | 25.61 | | | | | | | | 13.21 | | |

### JOHNSON GRASS

Johnson grass is the leading hay plant on the prairie limestone soils, and since so much of the hay contains mature seed there is comparatively little land on which Johnson grass is not a troublesome weed in cultivated crops. As the grass is widely distributed and has a high feeding value, information is needed regarding the methods of handling the crop to obtain the greatest possible revenue. Accordingly, tests have been conducted at this station for several years to determine the most desirable stage of harvesting the grass for hay and the cultural treatments essential to the largest yields. The plots have been cut at three stages of growth as follows: (1) Before bloom, (2) at bloom, and (3) after seed has matured. In these tests the yields have been slightly more from the grass which has formed seed before it was cut, but the quality of the hay was inferior. Such hay not only commands a lower price on the market but, because of its maturity, considerable waste results in feeding. Furthermore, manure carrying mature seed when spread on cultivated land tends to increase the weed problem. The yields obtained from Johnson grass harvested just before bloom and in full bloom have not differed appreciably, although the hay cut before blooming has been of a higher quality, and there is less waste in feeding. All results indicate that for the best quality of hay, Johnson grass should be harvested just before blooming, or, since Johnson grass blooms irregularly, as soon as a few scattering plants begin to bloom.

In the study of meadow management it has been rather definitely established that some kind of tillage is necessary to increase the vigor of Johnson grass and check the growth of wiregrass, which is especially troublesome on these soils. While the results of cultural treatments are not conclusive, uncultivated plots have contained over 50 percent of wiregrass in the earlier cuttings. Shallow plowing or heavy disking every 3 years has been of material assistance in improving the yield and quality of hay.

### SUDAN GRASS

As indicated by preliminary tests, results of which are given in table 16, Sudan grass can often be used to advantage as an emergency hay and pasture crop where Johnson grass is not already well established.

TABLE 16.—*Annual and average acre yields of air-dry Sudan grass from rows and broadcast seedings*

| Method of planting | 1926 | 1927 | 1928 | Average | |
|---|---|---|---|---|---|
| | | | | 1927–28 | 1926–28 |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| Broadcast | 1.84 | 3.19 | 1.46 | 2.33 | 2.16 |
| 3.3-foot rows | 2.41 | 2.48 | 1.25 | 1.87 | 2.05 |
| 1.65-foot rows | | 2.93 | 1.51 | 2.22 | |

### LESPEDEZA

In addition to common lespedeza (*Lespedeza striata*), two other annual lespedezas, Korean (*L. stipulacea*) and Kobe (*L. striata*), have been grown several years. Kobe lespedeza resembles the common sort in general appearance but has longer leaves and is more vigorous. Korean lespedeza is earlier maturing, coarser, and has broader and larger leaves than the common species. These annual lespedezas are not satisfactory hay crops on the heavy limestone soils, but may have a place in pasture mixtures. During the dry summer of 1930, Korean and Kobe lespedezas proved more drought resistant than common lespedeza. *L. sericea*, a perennial form, was sown in the spring of 1926 and the plants still survive. This lespedeza makes a growth of 6 to 8 inches the first season and 2½ to 3 feet subsequent seasons but does not appear promising on this soil. The seed has matured late in the season and very little volunteering has been observed. Both the annual and perennial forms would doubtless give more satisfactory results on the lighter-textured soils.

### VELVETBEANS

Velvetbeans can be grown successfully in this section, and they afford valuable grazing during the late fall and early winter months. The bush or bunch and vine varieties have been tested over a period of 4 years. While the results have not been tabulated, observations indicate that the vining varieties are the most desirable. The pods of the bush velvetbean usually form on or near the ground and therefore are often damaged by rain before maturity. The vining varieties are usually grown in combination with corn (fig. 7), and as they are difficult to harvest they are usually grazed. As a seed crop velvetbeans offer no serious competition with other legumes, as they must be hand-picked and are difficult to thresh because of the hard seed pod.

### SWEETCLOVER

The work with sweetclover has been confined largely to nursery seedings. Twenty varieties and strains have been tested, but none appear superior to the ordinary biennial white variety. Good results have been obtained from seedings made in early spring in winter oats, the oats being harvested for grain or hay, after which two crops of sweetclover hay are secured the first season. The following year the sweetclover is turned under when in full bloom as a soil-improvement crop. The biennial yellow strains of sweetclover being fine stemmed

produce a better quality of hay, but the biennial white sweetclover is more vigorous and more desirable for general use. Tests are under way to determine the comparative value of these two types for pasture and green manuring.

#### CROTALARIAS

Nursery plantings have been made of most of the species of *Crotalaria* and indications are that they are less dependable for soil improvement than soybeans. Since there is a serious doubt as to their palatability

FIGURE 7.—Velvetbeans in corn.

for stock feed, there is no good reason for growing them on a soil where clovers, alfalfa, and soybeans are adapted.

#### PIGEONPEAS

More than 200 strains of pigeonpeas have been tested, but none has shown any special merit. The behavior of the different strains varies from year to year, and the time of maturity is also uncertain. Those tested cannot compete with soybeans in this section

#### WINTER LEGUMES

For several years tests have been conducted to determine the adaptability of certain winter legumes as cover crops and for soil improvement. Of the legumes tested, Austrian winter peas and hairy vetch have proved most dependable. Crimson clover is fairly satisfactory if sown early. Hungarian vetch is hardy but has been much less productive than hairy vetch. Monantha vetch grows rapidly in the early fall but has failed to survive even the mild winters. The so-called "Canadian winter peas" have not proved hardy. Difficulty has been experienced in obtaining uniform stands of bur-clover, and

the growth has not been heavy. Tests are now under way to determine the comparative value of rye, crimson clover, hairy vetch, and Austrian winter peas as cover crops. Unfortunately, few of the winter legumes make growth sufficiently early to plow under for cotton, though they may be satisfactorily followed with corn, and have increased the yields of grain at the rate of 12 bushels per acre. Winter legumes should be sown in September or October, otherwise they may not become sufficiently established to survive the normal winters.

### CORN

The corn variety test has been carried on for 5 years to determine the most desirable variety for general use. This experiment has been conducted continuously on a plot of fairly uniform soil without fertilizers, which is the usual method of growing corn in this locality. Early and late varieties have been planted at the same time and treated similarly. The yields for each variety, as given in table 17, are based on the actual weights and shelling percentages, as determined by sampling at the time the weights were taken. It will be noted that these yields are low as compared with yields following alfalfa (p. 8), especially on those plots that had previously been fertilized, indicating the need for fertilizers in growing corn on these soils.

TABLE 17.—*Average and annual acre yields of grain of several varieties of corn*

| Variety | 1927 | 1928 | 1929 | 1930 | 1931 | Average |
|---|---|---|---|---|---|---|
| | *Bushels* | *Bushels* | *Bushels* | *Bushels* | *Bushels* | *Bushels* |
| Mosby's Station | 29.90 | 15.19 | 21.65 | 18.86 | 11.52 | 19.42 |
| Hasting's Prolific | 31.69 | 16.65 | 23.43 | 22.94 | 15.17 | 21.98 |
| Delta Prolific | 29.11 | 18.30 | 28.31 | 21.50 | 17.61 | 22.97 |
| Paymaster | 24.69 | 18.45 | 24.95 | 20.74 | 11.00 | 19.97 |
| Tennessee Red Cob | | | | | 11.18 | |
| Mexican June | 31.79 | 21.97 | 27.36 | 23.53 | 17.29 | 24.39 |
| Laguna | 30.45 | 23.72 | 26.15 | 22.86 | 17.91 | 24.22 |
| Goliad | 28.54 | 20.72 | 22.37 | 27.45 | 15.75 | 22.97 |
| Cocke's Prolific | 30.24 | 17.57 | 25.29 | 23.39 | | 24.12 |

### WINTER CEREALS

The tests with winter cereals have included several strains or varieties of oats, barley, wheat, and rye to determine their value for grain and as winter cover crops. None of the oats or barleys tested has proved entirely winter-hardy. During 2 of the 6 winters all varieties winter-killed practically 100 percent. The oats tested included Fulghum, Red Rustproof, and Hastings 100 Bushel. Rye and wheat have withstood all winter conditions for the past 6 years, and while the yields of grain have not been sufficient to justify sowing for this purpose alone, these crops appear to have value as a winter cover, alone and in combination with winter legumes. Abruzzi rye and Fulcaster wheat appear best adapted to general use. French and South Georgia rye are almost as satisfactory as Abruzzi rye for winter-cover purposes. Rosen rye does not make as early a growth as is desired for turning under for cotton.

### SUMMARY

The forage-crop field experiments near West Point, Miss., have been carried on in cooperation with the Mississippi Agricultural College and Experiment Station and were established primarily to determine causes of so-called "alfalfa failures" and if possible to find remedial measures.

The experiments are located on Houston or closely related soils.

The average annual rainfall over a period of 33 years amounted to 54.06 inches at Columbus, Miss., the nearest weather station with a continuous record.

The alfalfa acreage of the limestone prairie belt of Mississippi and Alabama increased more than 70 percent from 1909 to 1919 and decreased more than 77 percent from 1919 to 1924. The acreage since that time has remained fairly constant.

Strains of common alfalfa from Kansas, Utah, and the Dakotas have proved most satisfactory for this section. Alfalfas of the hardy group do not produce as much hay, and those of the nonhardy group are not sufficiently cold-resistant.

The best yields of alfalfa have been obtained from applications of stable manure alone or in combination with phosphatic fertilizers. Superphosphate and basic slag alone have also increased yields. Nitrogen and potash have not appeared to affect the growth.

Increased yields of corn have been obtained following alfalfa fertilized with phosphatic fertilizers and stable manures.

Alfalfa can be seeded either in spring or fall. Seeding should not be made later than April 15 in the spring or October 15 in the fall.

Too-frequent cutting has injured the stands of alfalfa. The safest stage of cutting in this section is when the new basal shoots appear.

Cultivation of alfalfa has not proved economically profitable, though no injury to the stands occurs when cultivated with a spring-tooth harrow with a modified type of tooth. The later cuttings contain less weeds.

No serious diseases are prevalent, but a few fields have been found to be affected with bacterial wilt, Fusarium wilt, and crown wart. Insect damage has been slight, the most common insect attacking alfalfa being the 3-cornered alfalfa leaf hopper.

Soybeans are well adapted to the prairie limestone belt and should be grown on areas not adapted to alfalfa. They are not so profitable as alfalfa for hay on the better types of limestone soil. Combinations of corn and soybeans have resulted in lower yields of corn, but they enable the grower to raise more feed on the same area.

The sorgos (sweet sorghums) are much more desirable than grain sorghums for forage.

Johnson grass should be cut for hay just before blooming or as soon as the first few blooms appear. Heavy disking or shallow plowing of the sod every 3 years increases the productivity.

Sudan grass sown broadcast is a good emergency hay crop where Johnson grass has not gained a foothold.

Sweetclover is adapted to about the same soils as alfalfa and will produce satisfactorily on soils of lower fertility.

Crotalarias, pigeonpeas, and velvetbeans are not so desirable as soybeans for annual summer legumes. Lespedezas do not make sufficient growth for hay on the heaviest soils.

Hairy vetch and Austrian winter peas are the two most promising winter legumes used.

Results of corn variety tests on land of medium fertility without fertilizer show very low yields.

Winter wheat and rye are useful as winter cover crops, alone or in combination with legumes. No dependable winter-hardy varieties of oats and barley have been found.

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# TRANSMISSION OF ANAPLASMOSIS BY VARIOUS SPECIES OF TICKS

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## INTRODUCTION

The problem of controlling anaplasmosis as a separate disease has developed in the United States because eradication of the cattle tick, *Boophilus annulatus*, over a large area in the South and the consequent eradication of piroplasmosis (tick fever) in that area have not been followed by the eradication of anaplasmosis. Eradication of anaplasmosis was at first expected to result from the eradication of the cattle tick, since the disease had been observed only in the cattle-tick area. However, later developments showed that it occurred also outside of this area. The purpose of the investigations conducted by the writer was to determine whether other species of ticks prevalent over wide areas of the country might also be vectors of anaplasmosis.

## REVIEW OF LITERATURE

### SPECIES OF TICKS INCRIMINATED

Smith and Kilborne (*19*)[1] noted the occurrence of "coccus-like bodies" in some of the experimental cattle to which they had previously transmitted piroplasmosis. It has been demonstrated by the work of Theiler (*20*) that these American authors were dealing with anaplasmosis, and that their experiments incriminated *Boophilus annulatus* as a vector of anaplasmosis as well as of piroplasmosis. Mohler (*8, p. 59*) reported the experimental transmission of a pure infection of anaplasmosis to 1 out of 4 head of susceptible cattle which were exposed to this tick.

[1] Italic numbers in parentheses refer to Literature Cited, p. 16.

Transmission of anaplasmosis by *Boophilus decoloratus*, an African species of the same genus as the North American cattle-fever tick, was demonstrated by Theiler (*21*). He first demonstrated the transmission, by this tick, of a mixed infection of piroplasmosis and anaplasmosis to a clean heifer that had been imported from England, and later demonstrated the transmission of anaplasmosis to two heifers which had been premunized [2] against piroplasmosis. The incubation periods were 75, 55, and 100 days, respectively. Finally, one generation of cattle-fever ticks was permitted to engorge on a horse; the next generation engorged on a clean calf to which, as was expected, the ticks did not transmit any disease. The third generation engorged on a heifer which carried anaplasmosis and gonderiosis, now known to be theileriosis, but which did not carry piroplasmosis. The larvae of the fourth generation were divided into two lots; one lot engorged on a calf that had been kept free from ticks, and another lot engorged on a heifer that was also known to be clean. Both the calf and the heifer contracted pure infections of anaplasmosis, the former reacting on the fifty-second day and the latter on the seventy-eighth day.

Theiler also incriminated *Rhipicephalus simus*. He collected engorged females from cattle in a region in which piroplasmosis and anaplasmosis were enzootic and permitted their larvae to engorge on a clean heifer. The incubation period was 75 days.

Quevedo (*10*, *11*) reported the transmission of mixed infections of piroplasmosis and anaplasmosis by *Boophilus microplus*, a South American species of the same genus as the cattle-fever tick of the United States.

Brumpt (*1*) reported that he could not confirm the work of Quevedo, but subsequently Brumpt (*2*) recorded an experiment which he performed in 1922 in which *Boophilus microplus* transmitted anaplasmosis after an incubation period of 175 days.

Rosenbusch and Gonzales (*16*, *17*) transmitted pure infections of anaplasmosis by *B. microplus*. They believed that a prevailing air temperature of 93° F. or higher was required for successful transmission. However, Brumpt's successful experiment previously noted was carried out when the mean temperature was between 59° and 63°.

Zeller and Helm (*22*) reported the experimental transmission of anaplasmosis to a cow by larvae of *Ixodes ricinus*. These larvae were the progeny of female ticks which engorged on a known carrier, the infection having been transmitted to it by an injection of bovine blood from an animal imported into Germany from Texas. The incubation period was 58 days. Helm (*4*) repeated the above experiment with success, the incubation period being 83 days.

Sergent, Donatien, Parrot, and Lestoquard (*18*) incriminated *Rhipicephalus bursa* and *Hyalomma lusitanicum* as vectors. Adults of the first species were picked from a native Algerian cow, and other adults were obtained from a known bovine carrier of anaplasmosis. These adults reattached to two head of susceptible cattle, and both of these animals developed anaplasmosis after incubation periods of 32 and 38 days, respectively.

For the experiment with *Hyalomma lusitanicum* an engorged female was taken in the market place from a native Algerian cow. This tick produced larvae which engorged on another bovine; the nymphs re-

[2] This term proposed by Sergent and associates (*18*) refers to a condition of a carrier's resistance less positive than immunity.

mained and engorged on the same host, *H. lusitanicum* being a two-host tick. The second bovine did not become infected; therefore, these ticks did not transmit anaplasmosis during engorgement while they were larvae and nymphs. However, they did transmit it to a third bovine on which they engorged when they became adults, the incubation period being 40 days. Brumpt (*2*) has pointed out that the test of susceptibility of the second bovine was not reported. This test was required to substantiate the claims of Sergent and his coworkers that the transmission was hereditary in the ticks and that larvae and nymphs which were infected with the etiological agent engorged without transmitting it. As Brumpt (*2*) has pointed out, the stage of the life cycle at which both *H. lusitanicum* and *Rhipicephalus bursa* become infected is not known.

Brumpt (*2*) recorded the experimental transmission of anaplasmosis by *Rhipicephalus bursa*. His experiment was performed in 1922, before that of Sergent and others (*18*), but was not recorded until 1931. Transmission was nonhereditary, that is, the larvae or the nymphs acquired the infection and the nymphs or the adults transmitted it. The incubation period was 34 days.

In previous papers by the present writer (*12*, *14*, *15*), 1 case of nonhereditary transmission by *Rhipicephalus sanguineus*, 4 cases by *Dermacentor variabilis* and 4 cases by *D. andersoni* were reported. In those tests the larvae or the nymphs became infected by engorging on a clinical case, and the nymphs or the adults which developed from these larvae transmitted the disease, the incubation period being, in all cases, about 30 days. All tests of hereditary transmission were negative for the above-mentioned species.

In the foregoing review the following 7 species of ticks belonging to 4 genera have been incriminated by other workers as transmitting anaplasmosis: *Boophilus annulatus*, *B. decoloratus*, *B. microplus*, *Rhipicephalus simus*, *R. bursa*, *Ixodes ricinus*, and *Hyalomma lusitanicum;* and 3 species have been incriminated by the present writer, *Rhipicephalus sanguineus*, *Dermacentor variabilis*, and *D. andersoni*, making a total of 10 species belonging to 5 genera incriminated throughout the world, exclusive of an additional species reported in this bulletin.

## METHODS OF REARING TICKS

Methods of rearing ticks were described and discussed by Lounsbury (*6*, *7*), who pointed out the difficulties of rearing 2-host and 3-host ticks on cattle. He experimented with stockings for the legs and with bags for the ears, for recovering the engorged larvae and nymphs which would otherwise drop into the stable litter and be lost. He noted that the thickness and the lack of vascularity of the skin of the legs and of the ears of cattle make these parts of the body undesirable for tick engorgement. Best results were obtained with bulls by confining the ticks in bags and attaching the latter to the bull's scrotum. Hooker, Bishopp, and Wood (*5*) used Lounsbury's methods when practicable and devised means of confining ticks on the ears of rabbits and dogs. Bags provided with drawstrings and protected by stiff leather collars were used on the ears. These collars were made by cutting out disk-shaped pieces of leather with holes in the center slightly larger than the necks of the animals. However, this method had its drawbacks because frequently, despite all precautions, the dogs and rabbits would scratch off the ticks. Very satisfactory re-

sults were obtained with smaller mammals by covering the latter with cloth bags and confining them in wire cages.

The following method of engorging ticks on rabbits has been developed at the Rocky Mountain Spotted Fever Laboratory at Hamilton, Mont., as reported by Morton (*9*):

> The rabbit's belly is clipped closely and two screen capsules are fitted to it by means of adhesive tape. The capsules are circular, about 3 inches in diameter, and are stamped from 20 mesh screening by a die, in such a fashion that the finished capsule has a circular depression ⅜ inch by 2 inches, surrounded by a ½-inch rim, somewhat the shape of a low-crowned hat. The rim fits tightly against the rabbit's belly and the ticks are fed within the depression.

A "longevity tube" has also been developed by the workers at the above-mentioned laboratory, in which unengorged ticks may be kept alive for any desired period up to 1 year, until they are needed for

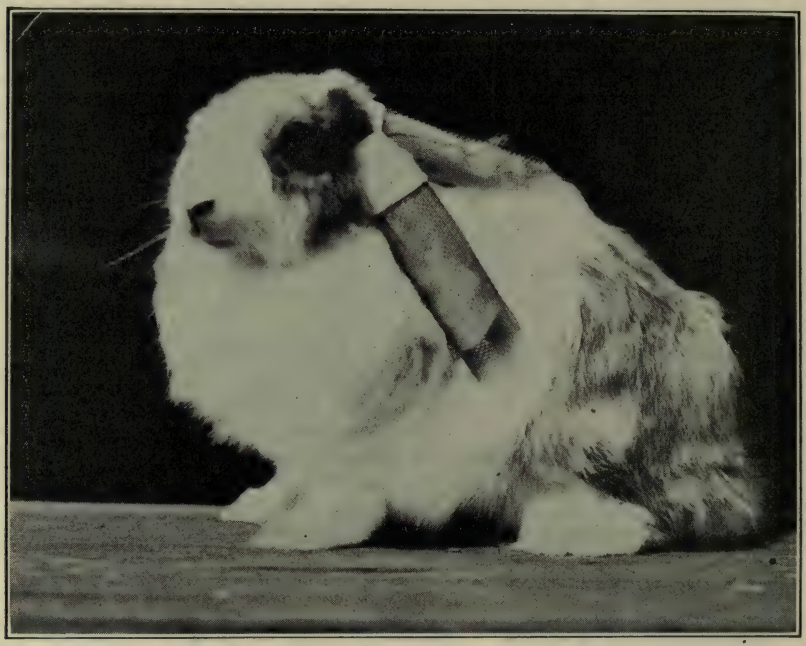

FIGURE 1.—A method of confining ticks in cloth bags, which are fastened by adhesive plaster on the ears of a rabbit and covered with cylinders made of fine-mesh copper screening.

experimental work. This tube is of Pyrex glass, is 1½ by 8 inches in size, and is plugged with clay at one end for a distance of about 2 inches, a piece of muslin being tied over the other end. According to Morton (*9*):

> A few pieces of dried leaves or shavings are placed inside the tube so the ticks will not be forced into direct contact with the wet clay plug. The tube is then placed out of doors in a 5 in. vertical hole in the tick yard, which keeps the clay plug in the tube always moist, and allows the ticks to seek the humidity within the tube which is most satisfactory to them.

DuToit (*3*) described and illustrated "pants" which were made to measure for cattle for collecting engorged larvae and nymphs of *Ixodes ricinus*. Drawstrings were provided at the "waist" and at the bottoms of the legs to prevent the escape of the ticks.

## IMPROVEMENTS IN THE TECHNIC OF REARING TICKS

The following improvements in the technic of rearing ticks have been made by the writer and were used in the present investigation.

Cloth bags were kept on the ears of rabbits by covering the bags with a cylinder of ordinary fine-mesh wire screen such as is used against mosquitoes. Such a cylinder is shown in figure 1. It has also been discovered that chicks from 2 to 10 weeks of age may be used advantageously for the engorgement of larvae and nymphs. The ticks were applied to the wings in bags made of silk bolting cloth, the larger feathers of the wings having been previously clipped. The process of engorgement may be observed through this thin cloth without removing the bags. The use of adhesive plaster by Morton (*9*) for fastening screen capsules to rabbits has been previously noted. The present writer found this material superior to drawstrings for fastening bags to the ears of rabbits, dogs, and cattle, the scrotum of bulls, and the wings of chicks. Garments similar to the ones described by duToit (*3*) were used on cows and steers except that elastic bands replaced the drawstrings as in the manufacture of clothing in recent years. These garments, which the writer has called "bloomers", are illustrated in figure 2.

FIGURE 2.—Bloomers used on cattle to collect larvae and nymphs of 3-host ticks.

## EXPERIMENTAL PROCEDURE

The experiments reported herein were performed under the same conditions as those described in previous publications by Rees (*12*, *13*, *14*, *15*). The problem involved the selection and maintenance of cattle that were known to be susceptible. Such cattle were purchased in a locality in southern Colorado where no disease resembling anaplasmosis is known to occur and were shipped during the late fall or winter to Jeanerette, La., and confined immediately in a specially constructed fly-proof barn. Susceptible cattle from Louisiana were

used also; by the operation of splenectomy it was possible to determine the susceptibility of the local cattle because in carriers there is a recurrence of symptoms. Anaplasmosis did not develop in any of the cattle except after experimental exposure either to infective ticks or to virulent blood by intravenous injection.

Steers 33 and 34, bulls 56, 57, 59, and 61, and heifers 58, 60, and 76, reported herein, were local cattle. Thirty-four bulls, steer 27, and heifer 32 were culled from dairy herds in Colorado for use in the experiments.

It was futile to attempt transmission of anaplasmosis by ticks to steers 33 and 34, which had evidently been premunized by a previous attack. However, the disease was successfully transmitted to the splenectomized susceptible heifer 76.

## RESULTS OBTAINED IN TESTS OF TRANSMISSION

Table 1 shows the results obtained in transmitting anaplasmosis by various species of ticks. Further data are given in the following case histories, which are more or less detailed according to the character of the tests and the significance of the results.

### AMBLYOMMA AMERICANUM (LINNAEUS, 1758)

#### TEST OF HEREDITARY TRANSMISSION

Adults engorged August 4–14, 1930, on bull 48, which had clinical anaplasmosis; larvae from their eggs were placed on bull 53 October 6–12; they engorged, but did not transmit disease; bull 53 was injected with blood from bull 47 May 25, 1931, reacted June 9, and died of anaplasmosis June 12.

#### TEST OF LARVA-TO-NYMPH TRANSMISSION

Larvae engorged October 2–13, 1930, on bulls 44 and 56, which had clinical anaplasmosis; resulting nymphs engorged November 3–11 on susceptible bull 49 but did not transmit anaplasmosis; test of susceptibility of host upon which nymphs engorged shown in following paragraph.

#### TESTS OF NYMPH-TO-ADULT TRANSMISSION

Nymphs engorged November 19–26, 1930, on bull 54, which had very severe anaplasmosis; as adults, were transferred December 27 to bull 49; engorgement terminated January 8, 1931, when the bull tore off the bag in which they were confined to the scrotum; several feamles about two thirds engorged; anaplasmosis not transmitted although susceptibility of bull was proved by injecting virulent blood February 9 from bull 61, to which injection bull 49 reacted March 3.

Nymphs engorged July 21–28 on bull 65, convalescing from anaplasmosis; adults were transferred August 18 to bull 64; four fully engorged females and a number of males and partly engorged females were recovered from this bull September 1 but did not transmit anaplasmosis; however, November 23 bull proved to be immune as he did not react to injection of blood from bull 67, which blood was known to be virulent.

### AMBLYOMMA CAJENNENSE (FABRICIUS, 1787)

#### TEST OF HEREDITARY TRANSMISSION

Adults engorged February 23–March 7, 1931, on bull 47 and March 3–21 on bull 49, both of which bulls had clinical anaplasmosis; resulting larvae engorged April 29–May 14 on bull 51, and May 5–12 on bull 62; anaplasmosis not transmitted; bull 51 reacted August 19 to injection, August 7, of virulent blood from bull 65 and died August 29; bull 62 contracted anaplasmosis during August 1931, transmitted by nymphs of *Dermacentor variabilis*, as reported by Rees (*16*).

TESTS OF LARVA-TO-NYMPH TRANSMISSION

Larvae engorged December 19–31, 1930, on bulls 56 and 59, both of which had clinical anaplasmosis; resulting nymphs engorged January 21–28, 1931, on bull 62 and February 2–18 on bull 53; anaplasmosis not transmitted; tests of susceptibility of bulls 62 and 53 noted previously.

Larvae engorged September 12–17, 1931, on bull 62 during an attack of clinical anaplasmosis; resulting nymphs engorged October 6–11, on bull 81 without producing anaplasmosis; susceptibility of animal tested in February 1932, by permitting infected nymphs of *Ixodes scapularis* to engorge; bull reacted to anaplasmosis April 2.

### AMBLYOMMA MACULATUM KOCH, 1844

TESTS OF HEREDITARY TRANSMISSION

Adults began to engorge February 5, 1931, on bull 61, which had clinical anaplasmosis; bull died February 12; partly engorged ticks were transferred to bull 56, a carrier of anaplasmosis, reattached, and completed engorging February 15; their larvae engorged March 27–31 on bull 65, without transmitting anaplasmosis; susceptibility of bull was demonstrated by injecting, June 16, virulent blood from bull 46, which resulted in development of anaplasmosis July 7.

Adults engorged December 21, 1931–January 4, 1932, on bull 62, a carrier of anaplasmosis; their larvae engorged February 26–March 4 on bull 69; bull did not develop anaplasmosis but proved to be immune when injected, June 1, with virulent blood from bull 89.

TESTS OF LARVA-TO-NYMPH TRANSMISSION

Larvae engorged November 25–December 9, 1930, on bull 54 and heifer 60, both of which had clinical anaplasmosis; resulting nymphs engorged December 20–31 on bull 46 and January 2–10, 1931, on bull 51; anaplasmosis not transmitted; bull 46 was found to be immune when injected April 13 with virulent blood from bull 49; test of susceptibility of bull 51 previously noted.

Larvae engorged October 20–26, 1931, on bull 62, which had passed through a reaction of anaplasmosis diagnosed as such September 2; resulting nymphs engorged November 12–20 on bull 83 but did not transmit anaplasmosis although susceptibility of bull was proved in March 1932, when adults of *Rhipicephalus sanguineus* transmitted the disease to it.

Larvae engorged February 4–12, 1932, on bull 65, a carrier of anaplasmosis; resulting nymphs engorged February 26–March 4 on bull 71 but did not transmit anaplasmosis; this bull after being injected May 23 with blood from bull 84, reacted June 9.

TEST OF NYMPH-TO-ADULT TRANSMISSION

Nymphs engorged January 8–16, 1931, on bull 56, which had a relapse of clinical anaplasmosis following splenectomy; as adults, engorged February 16–28 on bull 64; anaplasmosis not transmitted; however, bull was immune, as he did not react when injected November 23 with blood from bull 67, a proved carrier of the disease.

### BOOPHILUS ANNULATUS SAY, 1821

First generation engorged April 15–May 7, 1929, on steer 27, a known carrier; their larvae were placed on steers 33 and 34; anaplasmosis not transmitted; these animals were found to be immune when tested December 2, 1929, by injecting them with virulent blood from heifer 32, which had passed through a reaction of anaplasmosis diagnosed as such October 9, 1929.

Larvae on November 20, 1930, were placed on bull 54, which had very severe clinical anaplasmosis; adults were collected December 15–20; their larvae were transferred January 21, 1931, to bull 63; engorged females were picked off this animal, beginning February 12; anaplasmosis not transmitted; bull splenectomized March 3, sequelae uneventful, no reaction to anaplasmosis; bull was injected with blood from bull 49 May 14, anaplasmosis was diagnosed May 29, and bull 63 died May 31.

Larvae on April 24, 1931, were placed on bull 49, which had withstood an attack of anaplasmosis, was splenectomized April 1, and was undergoing a second reaction April 24; many engorged females were picked from bull May 20–28; their larvae were applied June 19 to bull 70; anaplasmosis not transmitted; test of susceptibility of bull given in following paragraph.

TABLE 1.—*Results obtained in transmitting*

| Name of tick | Exposure of ticks to etiological agent of anaplasmosis | | | | Exposure of susceptible bovines to ticks | |
|---|---|---|---|---|---|---|
| | Stage of tick engorging on infected bovine | Infected bovine no. | Stage of disease | Time of engorgement | Stage of tick used | Exposed bovine no. |
| *Amblyomma americanum* | Adult | 48 | Clinical | Aug. 4–14, 1930 | Larva | 53 |
| | Larva | 44 | do | Oct. 2–13, 1930 | Nymph | 49 |
| | do | 56 | do | Nov. 19–26, 1930 | Adult | 49 |
| | Nymph | 54 | do | July 21–28, 1931 | do | 64 |
| | do | 65 | do | Feb. 23–Mar. 7, 1931. | Larva | 51 |
| *A. cajennense* | Adult | 47 | do | Mar. 3–21, 1931 | | |
| | do | 49 | do | Feb. 23–Mar. 7, 1931. | Nymph | 62 |
| | do | 47 | do | Mar. 3–21, 1931 | | |
| | do | 49 | do | Dec. 19–31, 1930 | Nymph | 53 |
| | Larva | 56 | do | | | |
| | do | 59 | do | do | do | 62 |
| | do | 56 | do | | | |
| | do | 59 | do | Sept. 12–17, 1931 | do | 81 |
| | do | 62 | do | Feb. 5–15, 1931 | Larva | 65 |
| *A. maculatum* | Adult | 56 | Carrier | Dec. 21, 1931–Jan. 4, 1932. | do | 69 |
| | do | 61 | Clinical | Nov. 25–Dec. 9, 1930. | Nymph | 46 |
| | do | 62 | Carrier | do | do | 51 |
| | Larva | 54 | Clinical | Oct. 20–26, 1931 | do | 83 |
| | do | 60 | do | Feb. 4–12, 1932 | do | 71 |
| | do | 62 | Carrier | Jan. 8–16, 1931 | Adult | 64 |
| | do | 65 | do | Apr. 15–May 7, 1929. | Larva, nymph, and adult. | 33, 34 |
| | Nymph | 56 | Clinical | Nov. 20–Dec. 20, 1930. | do | 63 |
| *Boophilus annulatus* | Larva, nymph, and adult. | 27 | Carrier | Apr. 24–May 28, 1931. | do | 70 |
| | do | 54 | Clinical | July 13–Aug. 7, 1931. | do | 70, 66 |
| | do | 49 | do | Nov. 11–Dec. 4, 1931. | do | 89, 90 |
| | do | 65 | do | do | do | 101 |
| | do | 68 | do | Oct. 26–Nov. 5, 1931. | Larva | 85 |
| | Adult | (3) | | Nov. 2–11, 1931 | do | 86 |
| *Dermacentor andersoni* | do | 62 | Clinical | Dec. 10–20, 1931 | Nymph | 87 |
| | do | 67 | Carrier | do | do | 88 |
| | Larva | 66 | Clinical | Mar. 29–Apr. 4, 1932. | do | 89 |
| | do | 84 | do | Jan. 4–14, 1932 | Adult | 85 |
| | Nymph | 68 | do | do | do | 86 |
| | do | | do | May 20–26, 1931 | Larva | 71 |
| *D. variabilis* | Adult | 47 | do | do | do | 68 |
| | do | | do | July 7–14, 1931 | Nymph | 67 |
| | Larva | 65 | do | June 28–July 5, 1931. | do | 62 |
| | do | 46 | Carrier | July 14–22, 1931 | Adult | 73 |
| | Nymph | 65 | Clinical | do | do | 74 |
| | do | | do | Nov. 9–14, 1931 | do | 79 |
| | do | 68 | do | | | |

See footnotes at end of table.

*anaplasmosis by various species of ticks*

| Exposure of susceptible bovines to ticks—Continued | | | Check of susceptibility of nonreacting bovines | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Method | | | | | | |
| | | | By blood injection | | By exposure to other ticks | | | | |
| Time of engorgement | Result of exposure [1] | Period of incubation | Bovine no. | Date of injection | Species | Time of exposure | Result of test [1] | Period of incubation | Remarks [2] |
| | | Dy. | | | | | | Dy. | |
| Oct. 6–12, 1930 | − | | 47 | May 25, 1931 | | | + | 15 | Died. |
| Nov. 3–11, 1930 | − | | 61 | Feb. 9, 1931 | | | + | 22 | |
| Dec. 27, 1930–Jan. 8, 1931. | − | | 61 | do | | | + | 22 | |
| Aug. 18–Sept. 1, 1931. | − | | 67 | Nov. 23, 1931 | | | − | | |
| Apr. 29–May 14, 1931. | − | | 65 | Aug. 7, 1931 | | | + | 12 | Died. |
| May 5–12, 1931 | − | | | | *D. variabilis* | July 29–Aug. 15, 1931. | + | 35 | |
| Feb. 2–18, 1931 | − | | 47 | May 25, 1931 | | | + | 15 | Died. |
| Jan. 21–28, 1931 | − | | | | *D. variabilis* | July 29–Aug. 15, 1931. | + | 35 | |
| Oct. 6–11, 1931 | − | | | | *I. scapularis* | Feb. 2–10, 1932 | + | 60 | |
| Mar. 27–31, 1931 | − | | 46 | June 16, 1931 | | | + | 21 | |
| Feb. 26–Mar. 4, 1932. | − | | 89 | June 1, 1932 | | | − | | |
| Dec. 20–31, 1930 | − | | 49 | Apr. 13, 1931 | | | − | | |
| Jan. 2–10, 1931 | − | | 65 | Aug. 7, 1931 | | | + | 12 | Died. |
| Nov. 12–20, 1931 | − | | | | *R. sanguineus* | Feb. 13–29, 1932 | + | 33 | |
| Feb. 26–Mar. 4, 1932. | − | | 84 | May 23, 1932 | | | + | 17 | |
| Feb. 16–28, 1931 | − | | 67 | Nov. 23, 1931 | | | − | | |
| July 1–23, 1929 | − | | 32 | Dec. 2, 1929 | | | − | | |
| do | − | | 32 | do | | | − | | |
| Jan. 21–Feb. 12, 1931. | − | | 49 | May 14, 1931 | | | + | 15 | Died. |
| June 19–July 15, 1931. | − | | 68 | Feb. 26, 1932 | | | + | 20 | |
| Sept. 12–Oct. 8, 1931. | − | | 68 | do | | | + | 20 | |
| do | − | | 67 | Nov. 23, 1931 | | | + | 17 | |
| Jan. 4–30, 1932 | − | | | | *D. andersoni* | Apr. 18–26, 1932 | + | 38 | |
| do | − | | | | *R. sanguineus* | Apr. 21–28, 1932 | + | 35 | |
| June 18–July 15, 1932. | + | 63 | | | | | | | |
| Dec. 14–22, 1931 | − | | | | *D. andersoni* | Feb. 9–20, 1932 | + | 31 | (*) |
| do | − | | | | do | do | + | 30 | (*) |
| Jan. 4–12, 1932 | + | 29 | | | | | | | (*) |
| do | + | 30 | | | | | | | (*) |
| Apr. 18–26, 1932 | + | 38 | | | | | | | |
| Feb. 9–20, 1932 | + | 31 | | | | | | | (*) |
| do | + | 30 | | | | | | | (*) |
| June 30–July 8, 1931. | − | | 84 | May 23, 1932 | | | + | 17 | (*) |
| July 13–20, 1931 | − | | 62 | Oct. 24, 1931 | | | + | 13 | (*) |
| Aug. 4–15, 1931 | + | 31 | | | | | | | (*) |
| July 29–Aug. 15, 1931. | + | 35 | | | | | | | (*) |
| Aug. 10–21, 1931 | + | 34 | | | | | | | (*) |
| do | + | 35 | | | | | | | (*) |
| Dec. 21–30, 1931 | + | 30 | | | | | | | (*) |

TABLE 1.—*Results obtained in transmitting anaplas*

| Name of tick | Exposure of ticks to etiological agent of anaplasmosis | | | | Exposure of susceptible bovines to ticks | |
|---|---|---|---|---|---|---|
| | Stage of tick engorging on infected bovine | Infected bovine no. | Stage of disease | Time of engorgement | Stage of tick used | Exposed bovine no. |
| *Ixodes scapularis* | Adult | 87 | Clinical | Mar. 29–Apr. 14, 1932. | (4) | |
| | Larva | 42 | Carrier | Apr. 23–28, 1930 | Nymph | 44 |
| | do | | do | Apr. 28–May 4, 1930. | do | |
| | do | 73 | Clinical | Dec. 28, 1931–Jan. 4, 1932. | do | 80 |
| | | | | Jan. 4–11, 1932 | do | 80 |
| | | | | Dec. 28, 1931–Jan. 4, 1932. | do | 81 |
| *I. sculptus* | Adult | 57 | do | Jan. 29–Feb. 13, 1931. | Larva | 68 |
| | Larva | 54 | do | Nov. 18–25, 1930 | Nymph | 50 |
| | do | 58 | do | Oct. 4–28, 1930 | do | |
| *Rhipicephalus sanguineus* | Adult | 66 | do | Feb. 15–29, 1932 | Larva | 91 |
| | | | | | | 93 |
| | Larva | 41 | do | May 3–8, 1930 | Nymph | 43 |
| | do | 47 | do | Feb. 23–28, 1931 | do | 66 |
| | do | 49 | do | Mar. 3–8, 1931 | do | |
| | do | 50 | do | May 1–6, 1931 | do | 69 |
| | do | 62 | do | Sept. 2–9, 1931 | do | 76 |
| | do | 67 | Carrier | Mar. 24–29, 1932 | do | 90 |
| | Nymph | 79 | Clinical | Jan. 20–25, 1932 | Adult | 83 |
| | | | | | | 84 |

[1] (+) signifies positive reaction; (−) negative.
[2] Asterisks in this column refer to data previously reported by Rees (*12*, *14*, *15*) but included here for comparison.
[3] Taken from cow from Abbeville, La.

*mosis by various species of ticks*—Continued

| Exposure of susceptible bovines to ticks—Continued | | | Check of susceptibility of nonreacting bovines | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Method | | | | | | |
| | | | By blood injection | | By exposure to other ticks | | | | |
| Time of engorgement | Result of exposure [1] | Period of incubation | Bovine no. | Date of injection | Species | Time of exposure | Result of test [1] | Period of incubation | Remarks [2] |
| | | *Dy.* | | | | | | *Dy.* | |
| May 31–June 9, 1930. | − | | (3) | Aug. 29, 1930 | | | + | 39 | |
| Feb. 2–10, 1932 | − | | 84 | June 16, 1932 | | | + | 18 | |
| do | − | | 84 | do | | | | 18 | |
| do | + | 60 | | | | | | | |
| Mar. 31, 1931 | − | (4) | 62 | Oct. 24, 1931 | | | + | 13 | |
| Dec. 15–30, 1930 | − | | 49 | Apr. 10, 1931 | | | + | 20 | Died. |
| Apr. 4–9, 1932 | − | | 71 | July 19, 1932 | | | + | 21 | |
| do | − | | 81 | Aug. 5, 1932 | | | + | 14 | |
| May 25–June 2, 1930. | + | 32 | | | | | | | (*) |
| Mar. 25–Apr. 3, 1931. | − | | 67 | Nov. 23, 1931 | | | + | 17 | |
| May 25–June 2, 1931. | − | | 89 | June 1, 1932 | | | − | | |
| Sept. 30–Oct. 6, 1931. | + | 34 | | | | | | | Died. |
| Apr. 21–28, 1932 | + | 35 | | | | | | | |
| Feb. 13–29, 1932 | + | 33 | | | | | | | |
| do | + | 33 | | | | | | | |

[4] Failed to oviposit.
[3] Blood of sheep used.
[4] Failed to engorge.

Larvae on July 13, 1931, were placed on bull 65, during a very severe attack of anaplasmosis; many engorged females were collected August 7; bulls 66 and 70 were infested, September 12, with their larvae; anaplasmosis not transmitted; bull 66 was inoculated November 23 with blood from bull 67 and reacted December 10; bull 70, having withstood exposure to *Boophilus annulatus* for the second time, was injected February 26, 1932, with blood from bull 68 and reacted March 17.

Larvae on November 11, 1931, were placed on bull 68, which had clinical anaplasmosis; engorged females were removed December 4; their larvae were placed on bulls 89 and 90 January 4, 1932; many engorged adults were removed about 4 weeks later; anaplasmosis not transmitted; bulls were susceptible to anaplasmosis as the disease was transmitted April 18–26 to bull 89 by nymphs of *Dermacentor andersoni*, and April 21–28 to bull 90 by nymphs of *Rhipicephalus sanguineus*.

Larvae from an engorged female taken from an apparently healthy cow at Abbeville, La., were placed on bulls 71 and 101 on June 18, 1932; bull 71 was convalescing from anaplasmosis, having reacted June 9; bull 101 had never been exposed to the disease. On June 30, bull 71 had a temperature of 104° F., which continued until July 3 when it reached 107° and then subsided to normal. This reaction in an animal recently premunized to anaplasmosis was probably due to piroplasmosis, but no *Babesia* could be demonstrated. Bull 101 showed no reaction; was reinfested August 4 with larvae, the progeny of females which engorged on bull 71; reacted to anaplasmosis August 20, 63 days after the first exposure and 16 days after the second. The 63-day incubation period appears to be the more probable period of development, as it agrees with the ususal period for hereditary transmission, and the 16-day period is distinctly too short for development of the disease if transmitted by the tick.

#### DERMACENTOR ALBIPICTUS PACKARD, 1868

Two engorged females were received April 4, 1931, from J. E. Thompson of Ely, Minn., who had picked them from a moose; their larvae, which were transferred to bull 68 and heifer 60, were found on these animals for 15 days, but none appeared to have engorged; careful inspection was continued, but neither nymphs nor adults were detected. *Dermacentor albipictus* is a one-host tick.

#### DERMACENTOR ANDERSONI STILES, 1905

The data which incriminated this species as a vector of anaplasmosis have been published by Rees (*15*). The following test has been made since that time.

##### TEST OF LARVA-TO-NYMPH TRANSMISSION

Larvae engorged March 29–April 4, 1932, on bull 84 which had clinical anaplasmosis; resulting nymphs engorged April 18–26, on bull 89, which reacted May 26 to anaplasmosis, incubation period being about 38 days.

#### DERMACENTOR NITENS NEUMANN, 1897

Engorged adult females were received October 28, 1930, from J. H. Cooper of Raymondville, Tex; an attempt, beginning December 10, to cause their larvae to engorge on bull 54 was unsuccessful.

#### DERMACENTOR VARIABILIS SAY, 1821

The data which incriminated *Dermacentor variabilis* have been published by Rees (*15*). At that time the susceptibility of bulls 68 and 71, which failed to react in the test of hereditary transmission, had not been proved. This proof is now available.

##### TEST OF HEREDITARY TRANSMISSION

October 24, 1931, bull 68 was injected with blood from bull 62 and reacted November 6; May 23, 1932, bull 71 was injected with blood from bull 84 and reacted June 9.

##### TEST OF NYMPH-TO-ADULT TRANSMISSION

Another case of nymph-to-adult transmission has been produced as follows: Nymphs engorged November 9–14, 1931, on bull 68, which had clinical anaplas-

mosis; as adults, engorged December 21–30, 1931, on bull 79, which reacted to anaplasmosis January 20, 1932, the incubation period being about 30 days.

#### HAEMAPHYSALIS LEPORIS-PALUSTRIS NEUMANN, 1904

This tick occurs commonly on rabbits, especially during the spring and early summer. It has not been taken by the writer from any other host, but Hooker, Bishopp, and Wood (*5*) collected the larvae and nymphs from robins, quail, meadow larks, and several other birds, and from the domestic cat. Numerous attempts by the writer to engorge the larvae on bovines have failed; they were applied either on the ear, the scrotum, or in the flank region on the following dates: September 9 and September 14, 1929; February 10, February 28, May 9, May 12, June 18, June 23, and July 1, 1930; and April 18, 1932. As a rule several thousand larvae were applied at one time, although in several cases only one or two hundred were available. The larvae lived as long as 15 days without becoming engorged; on the other hand, engorgement occurred in about 4 days on the ears of rabbits and on the wings of chicks.

#### IXODES SCAPULARIS SAY, 1821

##### TEST OF HEREDITARY TRANSMISSION

Fourteen males and 11 females were placed March 29, 1932, on bull 87, which had clinical anaplasmosis; 3 fully engorged females dropped from bull April 12–14, 1932; they were kept in the laboratory and failed to oviposit, although all lived more than 30 days; hence this attempt to test hereditary transmission was incomplete.

##### TESTS OF LARVA-TO-NYMPH TRANSMISSION

Engorged females were collected from dogs by Louis Leonpacher and sent to the writer as follows: 4 on November 22, 1929, 2 on December 16, and 8 on December 23; only 2 oviposited and the eggs failed to hatch, being destroyed by fungi. Twenty engorged females, also collected by Dr. Leonpacher, were received during January and February 1930; all oviposited, and 14 of the egg masses produced larvae.

Several thousand larvae were placed April 23, 1930, on the ear of bull 42, a carrier of anaplasmosis; 61 completed engorgement and were recovered April 28, when other larvae were transferred to the scrotum of bull; 550 engorged larvae were recovered May 2 and May 4. The remaining larvae were placed, May 7, on bull 41, which had clinical anaplasmosis; bull died May 10 and larvae were lost. Twenty-six nymphs from larvae which engorged on bull 42 were transferred May 31 to bull 44; only 5 were recovered fully engorged June 9; anaplasmosis not transmitted although susceptibility of bull was proved by injecting August 29, blood from a sheep which had been injected 30 days previously from bull 48, a carrier of anaplasmosis, to which injection bull 44 reacted October 7.

Five engorged females were taken from cattle in Mississippi and sent to writer, November 4, 1931, by H. L. Robbins; 3 oviposited and eggs hatched; some of the larvae were transferred December 28 to bull 73, which had clinical anaplasmosis; many engorged larvae were removed January 2, 3, and 4, 1932; more larvae were permitted to engorge January 4 on this bull and were recovered January 9–11; resulting nymphs were divided February 2 into 2 lots and about 80 applied to each of 2 susceptible bulls, nos. 80 and 81; February 6–10, 26 engorged nymphs were recovered from bull 80, and 30 from bull 81. The latter animal reacted April 2 to anaplasmosis after incubation period of about 60 days. Bull 80 did not react; susceptibility tested by injection of blood from bull 84 on June 16, and anaplasmosis developed July 4.

##### TEST OF NYMPH-TO-ADULT TRANSMISSION

Large numbers of nymphs were placed on bull 42 in June 1930, but only 5 engorged, 2 males and 3 females; as adults, they were placed on a pup July 16 in attempt to save the strain; 1 fully engorged female was recovered July 23, kept in laboratory until September 15, but did not oviposit.

Twenty-four nymphs engorged February 2–8, 1932, on bull 88, which had clinical anaplasmosis; only 4 males and 4 females molted and on April 7 were placed on susceptible bull no. 80; none engorged, all being found dead April 12.

#### IXODES SCULPTUS NEUMANN, 1904

##### TEST OF HEREDITARY TRANSMISSION

Eighteen females and 16 males engorged January 29, 1931, on bull 57, which had clinical anaplasmosis; 6 engorged females were recovered February 6–13; their larvae were transferred March 31 to a susceptible bull, no. 68; so far as could be determined, no larvae engorged; bull was injected October 24, 1931, with blood from bull 62 and reacted to anaplasmosis November 6.

##### TEST OF LARVA-TO-NYMPH TRANSMISSION

Larvae engorged October 4–28, 1930, on heifer 58, having clinical anaplasmosis; other larvae engorged November 18–25 on bull 54, which also had clinical anaplasmosis. Two nymphs from the larvae of heifer 58, and 62 nymphs from bull 54, were confined on the scrotum of a susceptible bull, no. 50, December 15; 40 engorged nymphs were recovered December 30; did not transmit anaplasmosis. Bull 50 was injected April 10, 1931, with blood from bull 49, reacted April 30, and died of anaplasmosis May 6.

No tests of nymph-to-adult transmission with this tick have thus far been conducted.

#### RHIPICEPHALUS SANGUINEUS LATREILLE, 1806

One case of larva-to-nymph transmission has been published by Rees (*12*). Subsequent tests have been conducted with this species as follows:

##### TEST OF HEREDITARY TRANSMISSION

On February 15, 1932, adults were placed on bull 66, which had a second attack of anaplasmosis following splenectomy January 30; 67 engorged females and fully as many males were recovered February 24–29; on April 4 many thousands of their larvae were placed on bull 91 and on bull 93; larvae engorged and were recovered April 9; anaplasmosis not transmitted. Bull 91 was injected July 19 with blood from bull 71 and developed anaplasmosis August 9. Bull 93 was injected August 5 with blood from bull 81 and developed anaplasmosis August 19.

##### TESTS OF LARVA-TO-NYMPH TRANSMISSION

Larvae were confined on bull 47 February 23–28, 1931, and other larvae on bull 49 March 3–8, both of which bulls had clinical anaplasmosis. Very few larvae engorged and when they molted to nymphs only about 25 from both bulls could be collected. These were transferred March 25 to bull 66; 6 engorged and were recovered April 1–3, anaplasmosis not transmitted. Bull 66 was injected November 23 with blood from bull 67 and developed anaplasmosis December 10.

On May 1, 1931, larvae were placed on bull 50, which had clinical anaplasmosis; only 38 engorged, and were recovered May 6; 28 molted to nymphs and on May 25 were placed on bull 69; nymphs engorged and were recovered June 1–2; did not transmit clinically detectable anaplasmosis, but when the susceptibility of bull 69 was tested by injecting virulent blood from bull 89, June 1, 1932, bull 69 failed to react. A possible explanation is that a mild reaction may have occurred and this was not detected.

Larvae engorged September 2–9, 1931, on bull 62, which had clinical anaplasmosis; nymphs were transferred September 30 to heifer 76, which had been received from the dairy herd at the Jeanerette station and splenectomized August 26. Since no reaction to anaplasmosis occurred, the operation indicated that the heifer was susceptible. Twenty-one engorged nymphs were recovered October 5 and 6; heifer reacted to anaplasmosis November 3 and died November 9; incubation period was, therefore, about 34 days.

Larvae engorged March 24–29, 1932, on bull 67, a carrier of anaplasmosis; ticks engorged as nymphs April 21–28 on bull 90, which reacted to anaplasmosis May 26, 35 days after exposure to these nymphs.

##### TESTS OF NYMPH-TO-ADULT TRANSMISSION

On January 20, 1932, nymphs were placed on bull 79, which had clinical anaplasmosis; many engorged and were recovered January 24 and 25. Adults were transferred, February 13, to two susceptible bulls, nos. 83 and 84. On February 22–29, 12 engorged females and a number of males were taken from bull 83, and 7 engorged females, also a few males, from bull 84. Both bulls reacted to anaplasmosis March 17, 33 days after exposure to ticks.

## DISCUSSION

The work of previous investigators has established the fact that ticks are the natural intermediate hosts of the etiological agent of anaplasmosis, and futhermore that this etiological agent has little host specificity except that all ticks that have thus far been incriminated occur in the family Ixodidae. By incriminating one additional genus and 4 additional species, the present writer has confirmed and amplified the above general statements. It will be noted that the incrimination of *Ixodes scapularis* by the present writer for nonhereditary transmission was based on only one experiment, and additional work is desirable in order to confirm this finding, to determine the frequency with which transmission occurs, and to supply other data.

Nine experiments in the transmission of anaplasmosis by *Boophilus annulatus* have been conducted, although only eight head of cattle were used because bull 70, having failed to react to one generation of ticks, was exposed a second time to another generation before testing his susceptibility. Furthermore, two of the experiments with steers 33 and 34, respectively, were futile because these cattle were immune. Six other experiments were with negative results; the larvae with which the cattle were infested were the immediate descendants of ticks that had engorged either on demonstrated carriers or clinical cases. It appears that the successful transmission was by ticks which acquired their infection from a carrier under field conditions.

The fact is noteworthy that in the experiments conducted by the writer, with *Amblyomma americanum*, *A. cajennense*, *A. maculatum*, *Dermacentor andersoni*, *D. variabilis*, and *Rhipicephalus sanguineus*, hereditary transmission could not be demonstrated, although bull 69, which was exposed to larvae of *A. maculatum*, failed to react following the injection of virulent blood. However, before being used in the above test, bull 69 had been used in a test of larva-to-nymph transmission by *R. sanguineus*. Since transmission by this tick has been demonstrated by the writer, it is probable that immunity was developed in bull 69 by infection from this tick rather than from *A. maculatum*. Bulls 46 and 64 were also found to be immune after exposure to *A. maculatum*, the former to nymphs and the latter to adults. Bull 64 had previously been exposed also to *A. americanum*. It follows, therefore, that bulls 46 and 64 were (1) immune when purchased in Colorado, or (2) they acquired immunity by a mild attack during transit or during the time that they were held in the barn, before being used in the experiments, or (3) the ticks transmitted mild infections which were not detected clinically. Since anaplasmosis is not known to occur in southern Colorado and shipment of both bulls was made during cold weather, and since the bulls were held in a screened barn as described by Rees (*12*, *13*, *14*, *15*), exposure to ticks appears to be the most probable means of transmission. Further tests of both of the above-mentioned species of *Amblyomma* are, therefore, necessary.

## SUMMARY

The following contributions have been made by the writer to the technic of rearing ticks: (1) Chicks from 2 to 10 weeks of age may be used for the engorgement of larvae and of nymphs of various ticks; (2) adhesive plaster is superior to drawstrings for fastening bags to the ears of rabbits, dogs, or cattle, and to the scrotum of bulls; (3) cylinders

made of fine-mesh wire screen and fitted over the ears of rabbits serve to prevent them from scratching off the cloth bags in which ticks are confined; and (4) garments with elastic bands, designed to fit the bodies of cows and steers, are effective for the collection of engorged larvae and nymphs.

Eleven species of ticks belonging to 5 genera of the family Ixodidae have been incriminated throughout the world as vectors of anaplasmosis. These are as follows: *Boophilus decoloratus, B. microplus, B. annulatus, Dermacentor andersoni, D. variabilis, Hyalomma lusitanicum, Ixodes ricinus, I. scapularis, Rhipicephalus bursa, R. sanguineus,* and *R. simus;* that is, 3 species of the genus *Boophilus,* 2 of the genus *Dermacentor,* 1 of the genus *Hyalomma,* 2 of the genus *Ixodes,* and 3 of the genus *Rhipicephalus. Rhipicephalus sanguineus* is the most widely distributed of the above 11 species, occurring in Africa, Asia, Europe, North America, and South America.

The writer's contribution to this list of incriminated ticks includes one additional genus, *Dermacentor,* and four additional species, viz, *Rhipicephalus sanguineus, Dermacentor andersoni, D. variabilis,* and *Ixodes scapularis.*

Sixteen cases of nonhereditary transmission and one case of hereditary transmission of anaplasmosis have occurred at the Jeanerette, La., laboratory. In the former type of transmission, incubation period was 60 days in 1 case, and varied from 30 to 36 days in the other 15 cases. In the case of hereditary transmission the incubation period was 63 days.

All tests of hereditary transmission were negative, except in one case in which anaplasmosis was transmitted by *Boophilus annulatus.*

In six tests under conditions that appeared to be ideal—the larvae, nymphs, and adult ticks engorging on clinical cases—hereditary transmission by *Boophilus annulatus* as a vector could not be obtained, but in one case the disease was transmitted by seed ticks which were developed from a female engorged under field conditions on a cow that was presumably a carrier of anaplasmosis.

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TECHNICAL BULLETIN No. 417 MAY 1934

# BEEF PRODUCTION AND QUALITY AS INFLUENCED BY CROSSING BRAHMAN WITH HEREFORD AND SHORTHORN CATTLE

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## STATEMENT OF COOPERATION

The research work reported in this bulletin was conducted during the period 1924–27, by the United States Department of Agriculture, the Texas Agricultural Experiment Station, and the King Ranch, Kingsville, Tex.

During the first year, 1924–25, the work was conducted as an independent project. In the second year, 1925–26, the studies were associated with the cooperative project, a study of the factors which influence the quality and palatability of meat, in which the United States Department of Agriculture and a large number of the State agricultural experiment stations are engaged.

The following list of representatives of the cooperating agencies indicates the division of responsibility and coordination of activities:

*Administration.*—For the United States Department of Agriculture, E. W. Sheets and O. G. Hankins, Bureau of Animal Industry; for the Texas Agricultural Experiment Station, A. B. Conner.

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*Weights of parts and organs and other laboratory studies.*—J. L. Lush, Texas Agricultural Experiment Station; W. H. Black, A. T. Semple, K. F. Warner, P. E. Howe, N. R. Ellis, and F. C. Hilberg,[4] Bureau of Animal Industry; Armour & Co. and Swift & Co.

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[1] Resigned December 1929.
[2] Deceased.
[3] Services made available by the Purdue University (Ind.) Agricultural Experiment Station and the Nebraska Agricultural Experiment Station, respectively, together with the National Livestock and Meat Board and the Bureau of Animal Industry.
[4] Resigned July 1930.

TECHNICAL BULLETIN No. 417 MAY 1934

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

# BEEF PRODUCTION AND QUALITY AS INFLUENCED BY CROSSING BRAHMAN WITH HEREFORD AND SHORTHORN CATTLE

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(The Bureaus of Animal Industry, Agricultural Economics, and Home Economics in cooperation with the Texas Agricultural Experiment Station)

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## BRAHMAN CATTLE IN UNITED STATES

A few Brahman (Zebu) cattle, the humped cattle native to India, were introduced into South Carolina in 1849 and other small importations were made the next decade or shortly afterward. Some of these cattle reached Texas soon after the Civil War. However, Brahman cattle did not receive much public notice until 1906, when the large Pierce-O'Connor importation was made by A. P. Borden. Parr (*9, p. 13*)[1] and Mohler (*8*) give detailed information concerning this importation. Brahman cattle have been crossed extensively with the cattle of the coastal plains of Texas, with the object of producing larger, hardier, and more prolific cattle which would become fatter than the native cattle under the same conditions (*10, p. 16*). In the early years practically all crosses were made on herds of non-

[1] Italic numbers in parentheses refer to Literature Cited, p. 53.

descript cattle. However, during recent years a number of cattlemen in this region have built up grade Hereford, Shorthorn, and Aberdeen-Angus herds, on which they have sometimes used Brahman bulls or have bred Hereford, Shorthorn, Aberdeen-Angus, or Red Polled bulls to grade Brahman cows. Cattle having Brahman blood are found in considerable numbers along the Gulf coast from the Mexican border to southern Florida and are especially numerous from the region about Corpus Christi, Tex., to western Louisiana. A few Brahmans have been introduced into the southern parts of California, Arizona, and New Mexico and into western Texas and other sections of the range area.

Practically no attempt has been made to breed pure Brahmans for beef production. Instead, they have been used for crossbreeding, the most popular plan being to produce market cattle having from one fourth to one half Brahman blood. Most of these so-called Brahman cattle are sold to the packers by the ranchmen either direct or on the central markets. Large numbers of those that do not go direct from the ranch to the packing plant are shipped to Oklahoma or Kansas pastures and are grazed there through a spring and summer season. They are then sold on the central markets, and nearly all are bought by the packers. Very few Brahman cattle, even those containing only a little Brahman blood, are ever fed heavy grain rations in feed lots.

Though of nervous disposition, Brahman cattle quickly learn to know their feeder and become gentle if he is patient and quiet. Strangers and unusual disturbances tend to excite these cattle. Because of lack of experience with these cattle on the part of practical feeders and the possibility that these animals may furnish an important supply of raw material for the Nation's feed lots, it was thought desirable to determine experimentally how they compare in the feed lot with the better known beef breeds.

## PLAN OF EXPERIMENTS

Besides the usual feed-lot data, such as weights and gains, feed consumption, and selling prices, it was considered desirable to find out what differences, if any, existed between cattle of Brahman and non-Brahman breeding with respect to feeder and slaughter cattle grades and carcass grades, the various organs and parts, the proportions of the various cuts of meat, and the color, palatability, quality, and general desirability of the meat for market.

Opportunity to carry out such an experimental study was afforded by a cooperative agreement between the United States Department of Agriculture, the Texas Agricultural Experiment Station, and the King Ranch, Kingsville, Tex., by which the ranch supplied the cattle, feed, and equipment, and received the proceeds from the sale of the cattle; the Animal Husbandry Division of the Department of Agriculture furnished representatives to feed, weigh, and care for the cattle, keep the records, and report the progress of the experimental feeding; and the Texas station, assisted by the Animal Husbandry Division, collected and interpreted the slaughter data.

In addition, the second and third years' work were made a part of the cooperative project on factors which influence the quality and palatability of meat.

Approximately 100 steer calves and yearlings were fed each of three winters. Table 1 presents analyses of the feeds given. The steers were divided into four lots, care being taken to have them as nearly equal in every respect, except breeding, as the cattle available permitted. The live animals were graded at the market just before slaughter and the carcasses graded after being chilled. The pens in which the cattle were fed were approximately 72 by 86 feet. Each lot had a space of approximately 18 by 36 feet under an open shed on the north side of the lots. Descriptions of the cattle used are given in the reports of each year's work.

TABLE 1.—*Average analyses of principal feeds used during the 3 experiments*[1]

| Feed | Period of feeding | Analyses | Moisture | Ash | Crude protein | Crude fiber | Nitrogen-free extract | Ether extract |
|---|---|---|---|---|---|---|---|---|
| | | *Number* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Kafir and darso heads, ground | 1924–25 | 2 | 9.6 | 3.4 | 11.1 | 7.8 | 65.7 | 2.4 |
| Hegari heads, ground | 1925–26 | 1 | 15.9 | 4.0 | 8.5 | 6.0 | 64.1 | 1.5 |
| Do | 1926–27 | 2 | 9.0 | 4.5 | 10.9 | 14.6 | 58.4 | 2.6 |
| Threshed hegari, ground | 1926–27 | 3 | 12.6 | 1.6 | 11.9 | 2.4 | 70.1 | 1.4 |
| Shelled corn, ground | 1924–25 | 9 | 10.4 | 1.3 | 10.0 | 2.3 | 71.9 | 4.1 |
| Do | 1925–26 | 2 | 14.2 | 1.2 | 9.4 | 2.0 | 71.1 | 2.1 |
| Do | 1926–27 | 3 | 10.0 | 1.5 | 10.6 | 2.7 | 70.8 | 4.4 |
| Ear corn with husk, ground | 1925–26 | 2 | 10.5 | 1.8 | 8.5 | 9.8 | 66.1 | 3.3 |
| Cottonseed cake | 1924–25 | 3 | 8.2 | 5.7 | 43.0 | 11.1 | 25.4 | 6.6 |
| Do | 1925–26 | 5 | 8.3 | 5.8 | 41.9 | 10.7 | 26.8 | 6.5 |
| Do | 1926–27 | 4 | 6.6 | 5.8 | 43.6 | 11.4 | 26.0 | 6.6 |
| Silage (mostly red-top sorgo, some containing a little corn) | 1924–25 | 6 | 73.2 | 3.1 | 1.9 | 7.3 | 13.8 | .7 |
| Rhodes-grass hay | 1924–25 | 3 | 9.4 | 7.6 | 4.6 | 34.2 | 43.2 | .9 |
| Do | 1925–26 | 5 | 8.1 | 9.2 | 6.6 | 33.5 | 41.3 | 1.3 |
| Rhodes-grass hay (chopped) | 1926–27 | 5 | 8.2 | 8.3 | 4.8 | 32.5 | 44.9 | 1.3 |
| Hegari stover, chopped | 1926–27 | 6 | 12.0 | 10.0 | 6.1 | 28.8 | 41.4 | 1.7 |

[1] All analyses were made under the direction of G. S. Fraps, chief of the division of chemistry, Texas Agricultural Experiment Station.

## FEED-LOT AND MARKETING DATA

### THE 1924–25 EXPERIMENT

#### CATTLE USED

During the first year a direct comparison was obtained between Hereford and Brahman-Hereford steers and between Shorthorn and Brahman-Shorthorn steers. The Herefords and Brahman-Herefords were raised in the same or nearby pastures and were from the same herd of Hereford cows, some of which were purebred and the remainder very high grade (figs. 1 and 2). The Shorthorn and Brahman-Shorthorn steers were raised in the same pastures or near each other but on portions of the ranch apart from the Herefords and the Brahman-Herefords. The dams of these steers were purebred or very high-grade Shorthorns. The Brahman bulls which sired all the crossbred calves were high grades, carrying from about three fourths to seven eighths Brahman blood.

Five head of average calves from each of the four lots were shipped to Fort Worth, Tex., on October 28, 1924, shortly before the beginning of the experiment. There they were sold and slaughtered to determine what differences existed among the lots when they went on feed. The calves were in rather thin condition (figs. 3 and 4).

The 100 steer calves and yearlings that were selected at the same time as the 20 calves which were slaughtered were kept in a dry

FIGURE 1.—One of the best steers of the Brahman-Hereford group, at the end of the 1924–25 experiment.

FIGURE 2.—Brahman-Hereford group at the end of the 1924–25 experiment.

lot on a preliminary feed for nearly 4 weeks before the beginning of the feeding experiment. They had been dipped on October 23 and were free of ticks. One Brahman-Hereford steer had to be removed from the experiment during the fourth period on account of sickness caused, as the autopsy showed, by a short piece of baling wire evi-

FIGURE 3.—Brahman-Hereford calves selected for slaughter off grass in October shortly before the beginning of the 1924–25 experiment.

FIGURE 4.—Brahman-Shorthorn calves selected for slaughter off grass in October shortly before the beginning of the 1924–25 experiment.

dently swallowed by the animal. No other serious disturbance of health was observed.

During this experiment as well as the two following ones, the non-Brahmans tended to clean up their feed in a very short time after it was placed before them. The steers of Brahman breeding, on the other hand, ate at intervals throughout the day. This same difference

in feeding habits has been observed in other experiments. The quantity of feed given was regulated according to the thoroughness with which the steers cleaned up their feed bunks before the next feeding time and by the apparent eagerness of the steers for feed when feeding time approached.

The weather for the 6 months of the experiment was unusually dry. Heavy frost occurred or a little ice formed in the watering troughs a few times during the winter, but the afternoon temperatures, taken between noon and 3 p.m., averaged 75° F. for February and 77° for March. Late in April and in May it became warm enough for the heat to affect noticeably the appearance and behavior of the cattle.

About a third of the steers from each lot were shipped to Fort Worth and slaughtered after only 4 months of feeding. The rest were continued on feed 2 months longer. This was done to find whether there were differences in their performance during short feeding periods not parallel to the differences found after long feeding periods.

### FEEDS USED

The ration for each lot consisted of limited quantities of cottonseed cake and a full feed of ground grain and Rhodes-grass hay. Silage was fed during the first four of six 30-day periods. Several changes in the ration were made during the experiment as it was necessary to use such home-grown feeds as were available. The same changes were made in all lots. From the beginning of the experimental feeding, November 24, 1924, until February 22, 1925, a period of 90 days, the grain consisted of a mixture of darso and white kafir heads ground fine enough to crack all the grains. During the next 12 days a gradual change was made to the feeding of ground ear corn, husks included. As the supply of this feed became low, ground shelled corn was fed, the change being made gradually from March 14 to March 23.

The cottonseed cake used first was of the size known commercially as walnut size. Later, screenings from the production of the regular walnut-sized cake were used. The average of three analyses during the experiment was 43 percent of crude protein. The silage was made mostly from red-top sorgo, the remainder being corn silage and some mixed corn-and-sorgo silage.

The Rhodes-grass hay, which had been baled, was of good quality except that a few bales were too ripe. From time to time the material left in the bottom of the hay racks was cleaned out, weighed, and deducted from the quantities of hay fed, to obtain the quantities consumed.

### RATIONS AND DAILY GAINS

The grain ration was increased from about 6 or 7 pounds during the first 30 days to 15 or 16 pounds the fourth 30 days. The cottonseed-cake ration was a trifle more than 1 pound for the first 30 days and about 3.5 pounds during the fourth 30 days. Silage was fed at the rate of about 9 pounds a head daily during the first period and about 5 pounds during the second, third, and fourth periods. The hay ration was decreased from an average of more than 4 pounds during the first period to an average of 2 pounds the fourth period. During the fifth and sixth periods the rations remained practically constant.

The weights of the steers by periods are shown graphically in figure 5. Summaries of the results of the first 120 days' and last 59 days' feeding for the 1924–25 experiment are shown in table 2.

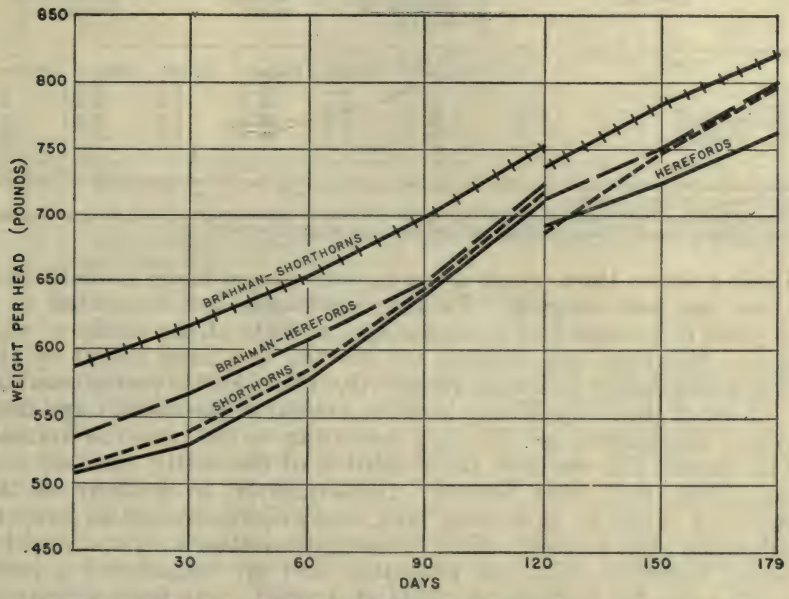


FIGURE 5.—Average live weights of the different lots during the first experiment, 1924–25.

TABLE 2.—*Average initial and final weights, daily gains, rations, and feed required per 100 pounds' gain*

FIRST 120 DAYS, NOV. 24, 1924–MAR. 24, 1925

| Breeding | Steers | Initial weight | Final weight | Daily gain | Daily feed per steer | | | | Feed per 100 pounds' gain | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Grain, ground | Cottonseed cake | Silage | Hay | Grain, ground | Cottonseed cake | Silage | Hay |
| | *Number* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| Hereford | 25 | 509 | 711 | 1.69 | 10.42 | 2.39 | 5.93 | 2.79 | 618 | 141 | 351 | 165 |
| Shorthorn | 25 | 513 | 714 | 1.68 | 10.90 | 2.51 | 5.93 | 3.37 | 648 | 149 | 353 | 201 |
| Brahman-Hereford | 24 | 536 | 724 | 1.57 | 11.20 | 2.55 | 5.98 | 3.09 | 713 | 162 | 381 | 196 |
| Brahman-Shorthorn | 25 | 588 | 753 | 1.38 | 12.17 | 2.79 | 5.93 | 4.29 | 883 | 203 | 431 | 312 |
| LAST 59 DAYS, MAR. 24, 1925–MAY 22, 1925 | | | | | | | | | | | | |
| Hereford | 17 | 694 | 762 | 1.17 | 11.99 | 2.37 | 0 | 1.98 | 1,028 | 203 | 0 | 170 |
| Shorthorn | 17 | 687 | 799 | 1.89 | 14.93 | 2.94 | 0 | 2.85 | 788 | 156 | 0 | 150 |
| Brahman-Hereford | 16 | 712 | 800 | 1.50 | 13.53 | 2.67 | 0 | 2.63 | 904 | 179 | 0 | 176 |
| Brahman-Shorthorn | 17 | 735 | 820 | 1.45 | 15.14 | 2.97 | 0 | 3.33 | 1,047 | 205 | 0 | 230 |

## MARKETING DATA

Table 3 shows the average amount and percentage of shrinkage per head between the final weights of the cattle on the ranch (6 miles from the shipping pens) and their sale weights in the stockyards at Fort Worth.

TABLE 3.—*Average shrinkage per head between feed lot and market,*[1] *1924–25*

| Breeding | Steers at beginning of experiment (average of 5 head) [2] | | Steers fed 120 days (average of 8 head) | | Steers fed 179 days (average of 16 or 17 head) | |
|---|---|---|---|---|---|---|
| | *Pounds* | *Percent* | *Pounds* | *Percent* | *Pounds* | *Percent* |
| Hereford | 15.0 | 3.3 | 47.2 | 8.8 | 36.5 | 4.8 |
| Shorthorn | 10.0 | 2.0 | 47.2 | 7.4 | 29.3 | 3.6 |
| Brahman-Hereford | 30.0 | 5.4 | 52.9 | 8.9 | 35.2 | 4.4 |
| Brahman-Shorthorn | 10.0 | 1.7 | 49.9 | 7.6 | 35.1 | 4.3 |

[1] The time between weighing in the King Ranch feed lots and in the Fort Worth stockyards was approximately 72 hours for each shipment.

[2] These are approximate weights; scale available for this determination weighed only to 5-pound units, hence all 5 calves in each lot were weighed together and total weight divided by 5.

Table 4 shows the average dressing percentages based on both final feed-lot and sale weights. Packing companies are interested in a high yield of carcass beef from the live weights of the cattle as purchased. However, sale weights are affected to a large extent by the shrink which occurs in the movement from feed lots to market and by the fill which the animals take between arrival at the market and time of sale. The shrink and fill vary according to the time the animals are in transit, the weather, the condition of the cattle, the feed and water given, and other factors. Consequently, in a study of the capacity of cattle for producing beef, sale weights are not an entirely satisfactory basis for computing dressing percentages. Final feed-lot weights, therefore, also are presented and are considered a more suitable basis for comparing yields of dressed meat from the steers used in these experiments.

TABLE 4.—*Average dressing percentages of experimental cattle, 1924–25*

| Breeding | Dressing percentages calculated from— | | | | | |
|---|---|---|---|---|---|---|
| | Sale weights and warm-carcass weights, shrunk 2.5 percent [1] | | | Final feed-lot weights and warm-carcass weights | | |
| | Steers at beginning of experiment (5 head) | Steers fed 120 days (8 head) | Steers fed 179 days (16 or 17 head) | Steers at beginning of experiment (5 head) | Steers fed 120 days (8 head) | Steers fed 179 days (16 or 17 head) |
| Hereford | 55.7 | 57.8 | 57.2 | 55.2 | 55.4 | 55.8 |
| Shorthorn | 54.3 | 55.7 | 56.6 | 54.6 | 53.9 | 55.9 |
| Brahman-Hereford | 56.3 | 59.5 | 59.4 | 54.6 | 56.6 | 58.3 |
| Brahman-Shorthorn | 55.4 | 59.2 | 61.4 | 55.8 | 56.8 | 60.2 |

[1] It is ordinary commercial practice to calculate dressing percentage on sale weights and warm-carcass weights which are shrunk a small percentage, predetermined from the average of a large number of carcasses to allow for the loss of water while the carcass is cooling.

Table 5 shows the average live-weight sale prices and appraised values of the carcasses per 100 pounds.

TABLE 5.—*Comparison of average live-weight sale prices and appraised values of carcasses, per 100 pounds,*[1] *for the 3 slaughter periods of the 1924–25 experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Live weight | Carcass | Live weight | Carcass | Live weight | Carcass |
| Hereford | $4.75 | $9.53 | $8.25 | $15.71 | $9.25 | $15.11 |
| Shorthorn | 4.00 | 7.77 | 7.75 | 13.81 | 9.25 | 14.89 |
| Brahman-Hereford | 5.00 | 9.13 | 9.00 | 14.67 | 9.25 | 14.23 |
| Brahman-Shorthorn | 4.75 | 8.67 | 8.50 | 13.50 | 8.75 | 13.38 |

[1] The live-weight prices are the prices actually paid for the live steers. The appraised values of the carcasses are the average of the values given to each carcass by 3 packer salesmen who worked independently, did not know what the cattle had cost alive, and were merely told to place on each carcass the price they thought they could get for it in their territory.

## THE 1925–26 EXPERIMENT

### CATTLE USED

In the 1925–26 experiment opportunity was provided to use second-generation Brahman-Shorthorn steers. These were the result of mating Brahman-Shorthorn bulls to Brahman-Shorthorn cows, each of which was of approximately the same breeding as the Brahman-Shorthorns of the previous experiment. However, as a result of the parents having been selected individuals from among a much larger number born in their generation, the second-generation steers were considered to be somewhat more desirable as beef animals than the first generation. To obtain experimental evidence on this point as well as to maintain the general purpose of the experiment, a lot of first-generation Brahman-Shorthorn steers also was included together with 1 lot of Shorthorns and 1 of Herefords as formerly. The Shorthorn lot included practically all the Shorthorn steer calves, 19 in number, available from the ranch's purebred herd. The other lots were selected from larger numbers. Most of the calves were born during February, March, and April 1925.

On October 26 and 27 the cattle were graded by the grading committee and put on preliminary feed. Representative calves from each lot were shipped immediately to Fort Worth for slaughter, to determine the killing qualities of the different lots at the time the feeding began.

On account of recent castrating and dehorning, some trouble was experienced with screw worms during the first month in the Shorthorn and first-generation Brahman-Shorthorn lots. On January 9 one of the first-generation Brahman-Shorthorns was taken out because it was in very poor condition and seemed likely to die. One of the Shorthorns died suddenly on February 10 from unknown cause.

### FEEDS USED

The feeding of all four lots began with coarsely ground ear corn in the husk, cottonseed cake, and Rhodes-grass hay. The cake was ground about as fine as ground corn so that it could be mixed more evenly with the grain. The hay was overripe and rather unpalatable, as indicated by the relatively small quantity consumed.

From January 5 to 25, ground hegari heads were fed. As they had been gathered during an unusually wet fall and stored in considerable bulk, some of the heads were slightly moldy. Most of these were picked out as the heads were going into the grinder. After all the hegari heads had been fed, ground shelled corn was substituted.

### RATIONS AND DAILY GAINS

Throughout this experiment the feeder endeavored to give the cattle all the concentrates they would clean up before the next feeding. By the middle of the first period the Herefords were eating 6 pounds of corn per head, the Shorthorns 5.5 pounds, the first-generation Brahman-Shorthorns 8.8 pounds, and the second-generation calves 7.2 pounds. After they were eating 10 pounds of grain per head, the ratio of grain to cake was kept at 5 to 1 throughout the experiment. In all the lots the consumption of hay dropped off considerably during the latter part of the first period, although hay was available to the steers at all times. Data on rations and gains are given in table 6. The weights of the steers by periods are shown graphically in figure 6.

TABLE 6.—*Average initial and final weights, daily gains, rations, and feed required per 100 pounds' gain*

| Breeding | Steers | Initial weight | Final weight | Daily gain | Daily feed per steer | | | Feed per 100 pounds' gain | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Grain, ground | Cottonseed cake | Hay | Grain, ground | Cottonseed cake | Hay |
| | *Number* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| **FIRST 120 DAYS, NOV. 6, 1925–MAR. 6, 1926** | | | | | | | | | | |
| Hereford | 24 | 437 | 670 | 1.94 | 11.09 | 2.42 | 1.75 | 572 | 125 | 90 |
| Shorthorn | 19 | 485 | 741 | 2.13 | 11.97 | 2.56 | 2.22 | 561 | 120 | 104 |
| Brahman-Shorthorn: | | | | | | | | | | |
| First generation | 24 | 584 | 810 | 1.88 | 14.36 | 2.92 | 3.06 | 764 | 155 | 163 |
| Second generation | 25 | 547 | 773 | 1.88 | 12.32 | 2.61 | 2.45 | 654 | 139 | 130 |
| **LAST 30 DAYS, MAR. 6–APR. 5, 1926** | | | | | | | | | | |
| Hereford | 17 | 668 | 715 | 1.58 | 13.17 | 2.64 | 1.91 | 832 | 167 | 120 |
| Shorthorn | 10 | 720 | 777 | 1.90 | 15.07 | 3.03 | 2.35 | 794 | 160 | 124 |
| Brahman-Shorthorn: | | | | | | | | | | |
| First generation | 16 | 793 | 840 | 1.55 | 15.64 | 3.13 | 3.48 | 1,007 | 201 | 224 |
| Second generation | 17 | 769 | 802 | 1.10 | 13.40 | 2.68 | 2.87 | 1,220 | 244 | 261 |

### MARKETING DATA

In the selection of the cattle to be shipped at the end of the fourth 30-day period, representative steers were picked out as far as possible. Tables 7, 8, and 9 present the comparative data on shrinkage, dressing percentages, and prices for the four lots. The very low prices for the first-generation calves in the shipment at the beginning of the experiment were caused by their being staggy and having practically no covering of fat. As shown in table 7, the first two shipments were marketed at Fort Worth, Tex., and the last at Kansas City, Mo. Since the distance to the Kansas City market was about twice that to Fort Worth, there is an opportunity to observe the effect of added time and distance on the shrinkage of the steers in the four lots.

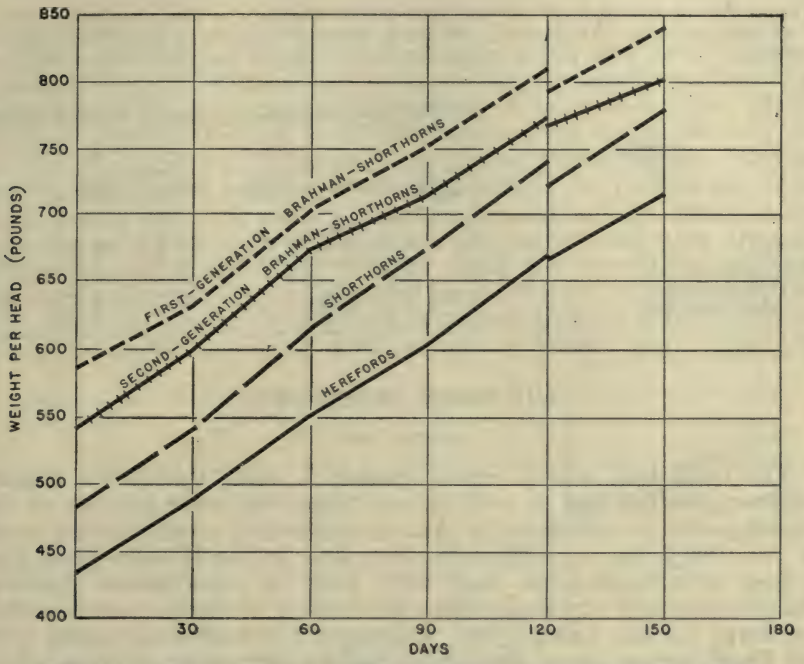


FIGURE 6.—Average live weights of the different lots during the second experiment, 1925–26.

TABLE 7.—*Average shrinkage per head in live weight between feed lot and market, 1925–26* [1]

| Breeding | Steers at beginning of experiment (4 or 5 head) | | Steers fed 120 days (6 to 9 head) | | Steers fed 150 days (10 to 15 head) | |
|---|---|---|---|---|---|---|
| | *Pounds* | *Percent* | *Pounds* | *Percent* | *Pounds* | *Percent* |
| Hereford | 29.6 | 7.6 | 51.7 | 7.6 | 50.4 | 7.0 |
| Shorthorn | 49.0 | 9.2 | 52.1 | 6.8 | 64.9 | 8.3 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 36.0 | 6.2 | 58.4 | 6.9 | 60.0 | 7.1 |
| Second generation | 38.0 | 6.9 | 59.1 | 7.6 | 60.3 | 7.4 |

[1] The first two shipments were marketed at Fort Worth, Tex., and the final shipment at Kansas City, Mo. The time elapsing between ranch feed-lot weighings and sale weighings at Fort Worth was approximately 72 hours. For the Kansas City shipment, the time was approximately 216 hours. The distance by rail from ranch shipping point to Fort Worth is 547 miles and to Kansas City 1,119 miles.

TABLE 8.—*Average dressing percentages of experimental cattle, 1925–26*

| Breeding | Dressing percentages calculated from— | | | | | |
|---|---|---|---|---|---|---|
| | Sale weights and warm carcass weights, shrunk 2.5 percent [1] | | | Final feed-lot weights and warm carcass weights | | |
| | Steers at beginning of experiment (4 or 5 head) | Steers fed 120 days (6 to 9 head) | Steers fed 150 days (10 to 15 head) | Steers at beginning of experiment (4 or 5 head) | Steers fed 120 days (6 to 9 head) | Steers fed 150 days (10 to 15 head) |
| Hereford | 53.3 | 58.5 | 58.6 | 50.5 | 55.4 | 55.8 |
| Shorthorn | 56.5 | 58.9 | 60.6 | 52.3 | 56.3 | 56.7 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 57.0 | 61.0 | 60.7 | 54.8 | 58.2 | 57.7 |
| Second generation | 57.3 | 60.6 | 61.2 | 54.7 | 57.5 | 57.8 |

[1] See footnote to table 4.

TABLE 9.—*Comparison of average live-weight sale prices and appraised values of carcasses, per 100 pounds,*[1] *for the 3 slaughter periods of the 1925–26experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Live weight | Carcass | Live weight | Carcass | Live weight | Carcass |
| Hereford | $6.00 | $9.93 | $9.35 | $16.71 | $9.00 | $13.97 |
| Shorthorn | 5.95 | 10.04 | 9.60 | 16.33 | 8.50 | 13.45 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 5.00 | 7.13 | 9.15 | 15.19 | 8.50 | 13.29 |
| Second generation | 6.82 | 12.43 | 8.85 | 15.81 | 8.50 | 13.34 |

[1] See footnote to table 5.

## THE 1926–27 EXPERIMENT

### CATTLE USED

The third test, which began October 6, 1926, included a supplementary feeding test as well as continuing the main purpose of the experiment. It was thought that the somewhat unsatisfactory gains of the first 2 years might have been due to the Rhodes-grass hay, a feed which has been used very little in experimental feeding. Results obtained previously from the feeding of this hay are reported by Fraps (*4*) and Tracy (*12*). Consequently, half of the steers were fed Rhodes-grass hay as a roughage and the remainder received hegari stover. The use of both these roughages also broadened the scope of the experiment somewhat by showing how the lots responded to the different feeds.

The cattle used were 98 yearling steers, of medium to good grade, which had been put on Rhodes-grass pasture and cottonseed cake to fatten. Of these steers, 25 were Herefords, 24 were Shorthorns, and 49 were Brahman-Shorthorns. Since the data already obtained on the comparative merits of first and second generation Brahman-Shorthorns were considered adequate, these groups were combined in the present phase of the experiment. The market and slaughter data obtained in the preceding 2 years from those feeder steers killed at the beginning of the experiment were deemed ample, and this line of study was therefore not continued.

### FEEDS USED

In order to continue the comparison of part-Brahman and non-Brahman cattle and at the same time conduct the roughage test, one lot of Herefords and Shorthorns and one lot of Brahman-Shorthorns were fed chopped Rhodes-grass hay, whereas another lot of Herefords and Shorthorns and another lot of Brahman-Shorthorns were fed chopped hegari stover. They were put on full feed gradually. When the supply of hegari grain was almost exhausted, ground shelled corn was gradually substituted. Cottonseed cake was fed to all lots.

The Rhodes-grass hay and hegari stover, which were chopped in a silage cutter, were fed very liberally to make certain that the cattle had all these roughages they could eat. During the last three periods some reduction was made in the roughage in order to increase the consumption of concentrates and hasten fattening.

### RATIONS AND DAILY GAINS

The part-Brahman lots consumed more grain and less roughage per steer and per 100 pounds of gain, on the average, throughout the feeding tests, than did the non-Brahmans. The part-Brahman steers reached their maximum grain consumption of approximately 15 pounds per head per day during the fourth 28-day period, whereas the non-Brahmans reached their maximum of 14 pounds per head daily during the fifth period. Roughage consumption was greatest with the part-Brahmans during the second period and with the non-Brahmans during the third period. Both the part-Brahmans and the non-Brahmans consumed more hegari stover than Rhodes-grass hay. During the period that each of the roughages was fed, the part-Brahman cattle consumed 9.40 pounds of hegari stover and 7.07

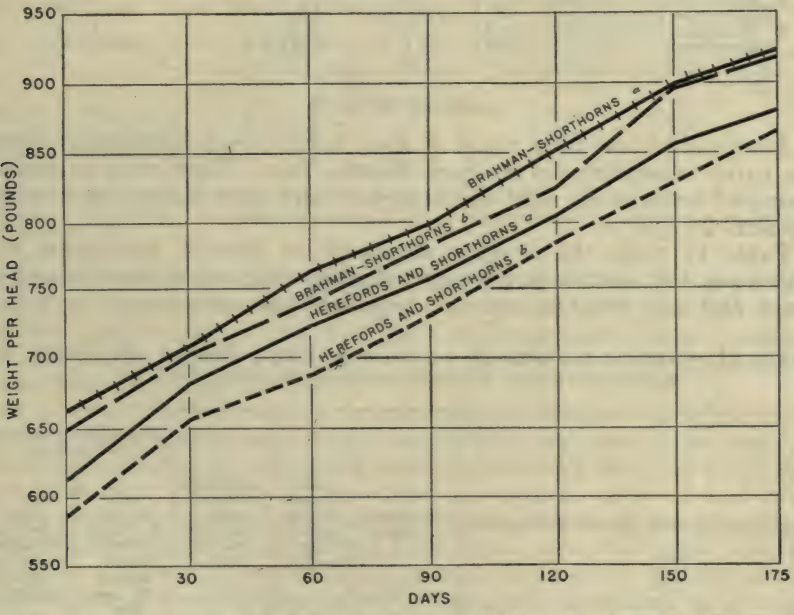


FIGURE 7.—Average live weights of the different lots during the third experiment, 1926–27: *a*, Fed Rhodes-grass hay; *b*, fed hegari stover.

pounds of Rhodes-grass hay per head daily, as compared with 10.64 pounds of stover and 8.79 pounds of hay consumed by the non-Brahmans.

During the first period the non-Brahmans made good gains, but during the rest of the experiment their gains were not satisfactory when compared with the quantities of feed consumed. The same was true of the part-Brahman lots, except for one period when the lot fed hegari stover gained more than 2 pounds per steer daily.

A summary of the daily gains, daily rations, and feed required per 100 pounds of gain is given in table 10. The weights of the steers by periods are shown graphically in figure 7.

TABLE 10.—*Average initial and final weights, daily gains, rations, and feed required per 100 pounds' gain during the entire feeding time of 175 days, Oct. 6, 1926–Mar. 30, 1927*

| Breeding and number of cattle and feed used | Initial weight | Final weight | Daily gain | Daily feed per steer | | | Feed per 100 pounds, gain | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Grain, ground | Cottonseed cake | Roughage | Grain, ground | Cottonseed cake | Roughage |
| Non-Brahman lots: | | | | | | | | | |
| 13 Hereford, 11 Shorthorn (fed Rhodes-grass hay) | *Lb.* 614 | *Lb.* 880 | *Lb.* 1.52 | *Lb.* 11.13 | *Lb.* 2.87 | *Lb.* 8.79 | *Lb.* 732 | *Lb.* 189 | *Lb.* 578 |
| 12 Hereford, 13 Shorthorn (fed hegari stover) | 588 | 863 | 1.57 | 10.30 | 2.78 | 10.64 | 656 | 177 | 678 |
| Part-Brahman lots: | | | | | | | | | |
| 24 Brahman-Shorthorn (fed Rhodes-grass hay) | 662 | 922 | 1.49 | 12.72 | 2.90 | 7.07 | 856 | 195 | 476 |
| 25 Brahman-Shorthorn (fed hegari stover) | 650 | 918 | 1.53 | 12.44 | 2.94 | 9.40 | 812 | 192 | 614 |

## MARKETING DATA

After individual final weights were taken for 3 consecutive days, the cattle were shipped to Fort Worth, Tex. They were in transit about 44 hours, were sold the next day, and were slaughtered within the next 2 days.

Table 11 gives the average shrinkage in transit, the actual sale prices per 100 pounds live weight, the dressing percentages based on ranch and sale weights, and the appraised carcass values.

TABLE 11.—*Average shrinkage in transit, sale prices, dressing percentages, and appraised carcass values of experimental cattle, 1926–27*

| Breeding and number of cattle and feed used | Shrinkage in transit | | Sale price per 100 pounds' live weight | Appraised carcass values per 100 pound weight | Dressing percentages calculated on— | |
|---|---|---|---|---|---|---|
| | | | | | Sale weight and warm carcass weight shrunk 2.5 percent [1] | Final feed-lot weights and warm carcass weights [2] |
| Non-Brahman lots: | | | | | | |
| 13 Hereford, 11 Shorthorn (fed Rhodes-grass hay) | *Lb.* 48 | *Percent* 5.46 | *Dollars* 9.00 | *Dollars* 14.53 | *Percent* 58.1 | *Percent* 56.3 |
| 12 Hereford, 13 Shorthorn (fed hegari stover) | 46 | 4.29 | 8.50 | 14.49 | 55.9 | 54.9 |
| Part-Brahman lots: | | | | | | |
| 24 Brahman-Shorthorn (fed Rhodes-grass hay) | 41 | 5.02 | 9.00 | 14.64 | 60.1 | 58.5 |
| 25 Brahman-Shorthorn (fed hegari stover) | 37 | 4.44 | 9.00 | 14.82 | 60.0 | 58.8 |

[1] See footnote to table 4.
[2] See footnote to table 5.

## DISCUSSION OF DATA

Table 12 summarizes the average performance of the Hereford and Shorthorn steers as contrasted with those containing Brahman blood. The preceding tables provide an opportunity for more specific comparisons of the various groups for the 3 years.

In daily gain, as shown in tables 2, 6, and 10, the non-Brahman lots excelled, though the degree of difference varied considerably, especially late in the fattening periods. For instance, in the last 30 days of the second year the non-Brahmans excelled the part-Brahmans in average daily gains by about 24 percent; whereas during the following year, for the entire feeding period, the corresponding difference was less than 3 percent. On the whole the daily gains of the Herefords and Shorthorns were moderately greater than those of the Brahman crossbreds.

TABLE 12.—*Differences between experimental lots of non-Brahman and part-Brahman steers with respect to various factors in beef production (average of all experiments)*[1]

| Breeding | Daily gain | Economical use of feed | | Low shrinkage, feed lot to market | Sale price per 100 pounds live weight | Dressing percentage | Appraised value of carcass per 100 pounds |
|---|---|---|---|---|---|---|---|
| | | Concentrates | Roughage | | | | |
| Hereford and Shorthorn | ++ | ++ | + | | | | ++ |
| Brahman-Hereford and Brahman-Shorthorn | | | | + | + | +++ | |

[1] +=slight superiority; ++=moderate superiority; +++=superiority highly significant statistically (*P* is less than 0.01).

In connection with these data, the nervous disposition of the Brahman crossbreds probably was responsible in part for their making smaller gains than did the non-Brahmans. The handling incident to the monthly weighings was observed to excite them much more than the other breeds.

In quantity of feed per 100 pounds of gain, as shown in tables 2, 6, and 10, the non-Brahmans consumed, with a few exceptions, considerably less grain and cottonseed cake and slightly less hay than the part-Brahmans. However, when this is expressed as total feed consumed per 100 pounds of live weight, there is practically no difference. The part-Brahmans ate their feed a little at a time but came back to the feed troughs and hay racks many times during the day for more, whereas the non-Brahmans usually consumed their feed in a comparatively short period.

In percentage of shrinkage in live weight between feed lot and market (tables 3, 7, and 11) the non-Brahman lots shrank less the first year, but in the next 2 years their shrinkage was greater. Differences in most cases were small with the net difference for the 3 years, with respect to low shrinkage, slightly in favor of the part-Brahmans.

Average sale prices per 100 pounds of live weight were greater for the non-Brahman lots during the second year (table 9), but for the first and third years, the difference, though slight, was in favor of the part-Brahmans (tables 5 and 11). On the average the Brahman-Herefords and Brahman-Shorthorns sold for slightly more, per 100 pounds of live weight, than the Herefords and Shorthorns, but the differences were so inconsistent from one marketing to another that the average difference is not significant.

Dressing percentages (tables 4, 8, and 11) of the steers of Brahman breeding were consistently greater than those of the non-Brahmans. The usual difference was between 2 and 4 percent, with an average of 2.4. This difference is significant from a market standpoint because of the greater yield of meat from the same weight of live animal. The differences for the various lots were so consistent that the higher dressing percentage of cattle of Brahman breeding is indisputable.

In appraised values of carcasses per 100 pounds of weight, as shown in tables 5, 9, and 11, the non-Brahman lots were slightly higher than the part-Brahmans for the first 2 years and slightly lower the last year. The small net difference was in favor of the non-Brahmans.

The average appraised values of the non-Brahman carcasses were slightly higher than those of the part-Brahman. In view of the fact that there was essentially no difference between the live-weight sales prices, the higher dressing percentage of the part-Brahmans offset their slightly lower carcass value per pound.

The comparison of first- and second-generation Brahman-Shorthorn steers for desirability as beef animals showed no consistent advantage of one group over the other. Although the second-generation steers were the result of more selective breeding, measurable differences for the entire experiment were slight. As seen in table 6, daily gains for the first 120 days were the same, but during the last 30 days the first-generation steers gained considerably more. Table 6 also shows that although the first-generation lot consumed more feed per 100 pounds of gain during the first 120 days, they consumed less during the last 30 days, there being, on the whole, practically no difference in feed consumption between the two lots. Average shrinkage in live weight between feed lot and market, as shown by table 7, was somewhat higher in the case of the second-generation lot. Dressing percentages (table 8) were practically the same for the two lots. Live-weight sale prices and appraised values of carcasses per 100 pounds (table 9) for the second generation were considerably higher at the beginning of the experiment but showed very little difference afterward.

From the standpoint of the producer or rancher raising and marketing steers for beef under the conditions in which these experiments were conducted, table 13 offers some noteworthy comparisons. In the 2 years that sample shipments of steer calves were made direct from grass the part-Brahman steers made gross returns of $26.35 and $31.42 per steer, respectively, as against $20.45 and $24.53 for the non-Brahman steers. Difference in returns of $5.90 and $6.89 are of great significance to the producer selling calves off grass at weaning time. As an average for the 2 years the part-Brahman calves weighed 91 pounds more per head and sold for about $0.28 more per hundredweight, than the non-Brahman calves.

When similar calves were placed in the dry lot and fattened for periods ranging from 120 to 179 days, the differences were not consistently in favor of either group. If the returns, less feed charges, for the first 120 days of feeding in the 1924–25 experiment are averaged with the corresponding results in 1925–26, a difference of $0.84 per head is obtained in favor of the part Brahmans.

TABLE 13.—*Sale weights and prices and gross returns, for steers marketed at various stages of fattening*

| Time of marketing | Non-Brahman | | | | | Part-Brahman | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Head | Average sales weight per steer | Average sale price per hundredweight | Average gross return per steer | | Head | Average sales weight per steer | Average sale price per hundredweight | Average gross return per steer | |
| | | | | Total | Less feed charges | | | | Total | Less feed charges |
| | *Number* | *Lb.* | *Dollars* | *Dollars* | *Dollars* | *Number* | *Lb.* | *Dollars* | *Dollars* | *Dollars* |
| 1924–25 experiment: | | | | | | | | | | |
| At beginning of experiment | 10 | 470 | 4.38 | 20.45 | ------- | 10 | 541 | 4.88 | 26.35 | ------- |
| After 120 days | 16 | 699 | 8.00 | 55.92 | 24.04 | 16 | 706 | 8.75 | 61.78 | 26.85 |
| After 179 days | 33 | 749 | 9.25 | 69.28 | 14.41 | 33 | 775 | 9.00 | 69.75 | 10.12 |
| 1925–26 experiment: | | | | | | | | | | |
| At beginning of experiment | 9 | 417 | 5.88 | 24.53 | ------- | 10 | 528 | 5.95 | 31.42 | ------- |
| After 120 days | 15 | 678 | 9.50 | 64.41 | 35.74 | 16 | 753 | 9.00 | 67.77 | 34.60 |
| After 150 days | 27 | 682 | 8.81 | 60.08 | 21.42 | 33 | 760 | 8.50 | 64.60 | 20.94 |
| 1926–27 experiment: | | | | | | | | | | |
| After 175 days | 49 | 824 | 8.75 | 72.10 | 19.64 | 49 | 881 | 9.00 | 79.29 | 23.13 |

After the feeding period of 150 days in 1925–26, however, there was a difference of $0.48 in favor of the non-Brahmans. Moreover, when the results of the 179-day period in 1924–25 are averaged with those of the 175-day period in 1926–27 a difference of $0.40 a head is obtained in favor of the non-Brahmans.

Thus it will be observed that the part-Brahmans show to better advantage than the non-Brahmans when fed for a period not exceeding 120 days when gross sale price less feed charges is used as the basis for comparison.

The experiments indicate that as a rule steers of Brahman breeding will not gain weight so rapidly in feed lots during a long feeding period as Hereford and Shorthorn steers. The difference is small but fairly consistent. Data published by the Texas Agricultural Experiment Station (*5*, *6*, *7*) support the conclusion that cattle of Brahman breeding gain weight less rapidly in feed lots than Herefords. These data also show that the former grow more rapidly on the range and pastures before being sent to the feed lot. In comparisons at the Texas Station, first-generation Brahman-Herefords gained less rapidly in feed lots than Herefords. In most cases they also weighed more than the Herefords when taken from pasture and placed in the feed lot.

The data on dressing percentages, in the present study, indicate that the superiority of Brahman crossbreds in this respect increases as the feeding period becomes longer.

Some of the observed differences in these studies may be the general effect of crossbreeding resulting in so-called hybrid vigor or heterosis. Others are doubtless the result of characteristics peculiar to Brahman cattle. Only such of the latter as were dominant or intermediate in inheritance could be observed under the conditions of these experiments.

## WEIGHTS AND SIZES OF VARIOUS ORGANS AND OTHER PARTS OF BODY, 1924–27

Brahman cattle and the beef breeds of European origin are so different in body conformation that it was thought desirable to determine whether there are significant differences in the weight or size of important vital organs and also of the heads, hides, and other parts of the body that have a bearing on the value of the animals and their products. The packing plants which purchased the cattle extended full cooperation in this study even though the large amount of weighing and measuring interrupted their schedules.

Nearly all parts were weighed as soon as the butchers separated them from the carcasses. Hides were laid aside in the hide cellar until the other data had been obtained and then were weighed and measured at the first opportunity. There were a few mishaps, such as tags becoming torn off or numbers becoming illegible; these account for slightly varying numbers of animals represented in some of the data.

At the earlier slaughterings, nearly all parts which could be weighed with fair accuracy were included. The data were studied after each slaughtering to determine whether there were any significant differences among the lots. In later slaughterings, parts which appeared to have no significant difference were omitted unless they were of considerable economic or physiological importance.

The weights of certain parts, such as heads, hides, and hearts, are associated to some extent with body weight. Since the different groups of steers were not usually equal in average live weight, it was obviously desirable to express many of the data as percentages of body weight.

Special considerations apply also to certain parts. For example, the percentage of weight of head to live weight is very distinctly influenced by age, being larger for younger cattle than for older ones. Also certain tissues such as caul fat, ruffle fat, and paunch fat are intimately related to the degree of fatness of the entire steer. Final feed-lot weights rather than sale weights were used to avoid differences in shrinkages and fills, yet of course even the weights used were influenced slightly by the varying quantities of feed in the digestive tract. Computations were carried to the last decimal place considered possibly significant, depending on the character of the scale used and on the exactness of the experimental methods.

### WEIGHTS OF HEADS, TONGUES, AND BRAINS

Table 14 gives the number of cattle in each lot from which slaughter data were obtained and a comparison of weights of heads (exclusive of tongues) with the final feed-lot weights of animals. All the subsequent tables of weights of parts are based on the numbers of steers shown in table 14, unless exceptions are noted.

TABLE 14.—*Comparison of average weights of heads (exclusive of tongues) of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | | | Steers fed 120 days | | | | Steers fed 179 days [1] | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Animals slaughtered | Final weight of steer | Weight of heads | | Animals slaughtered | Final weight of steer | Weight of heads | | Animals slaughtered | Final weight of steer | Weight of heads | |
| | | | Average | Percentage of final weight of steer | | | Average | Percentage of final weight of steer | | | Average | Percentage of final weight of steer |
| | *Number* | *Lb.* | *Lb.* | | *Number* | *Lb.* | *Lb.* | | *Number* | *Lb.* | *Lb.* | |
| Hereford | 5 | 455 | 14.7 | 3.23 | 8 | 731 | 18.5 | 2.53 | 17 | 762 | 19.0 | 2.50 |
| Shorthorn | 5 | 510 | 15.8 | 3.10 | 8 | 762 | 18.8 | 2.46 | 16 | 803 | 19.8 | 2.47 |
| Brahman-Hereford | 5 | 552 | 15.8 | 2.87 | 8 | 735 | 18.3 | 2.49 | 16 | 800 | 19.4 | 2.42 |
| Brahman-Shorthorn: | | | | | | | | | | | | |
| First generation | 5 | 570 | 17.1 | 3.00 | 8 | 780 | 18.7 | 2.40 | 17 | 820 | 19.9 | 2.42 |
| 1925–26 EXPERIMENT | | | | | | | | | | | | |
| Hereford | 5 | 392 | 12.0 | 3.08 | 6 | 678 | 17.1 | 2.52 | 15 | 721 | ..... | ..... |
| Shorthorn | 4 | 534 | 15.3 | 2.87 | 9 | 764 | 18.0 | 2.36 | 10 | 777 | ..... | ..... |
| Brahman-Shorthorn: | | | | | | | | | | | | |
| First generation | 5 | 578 | 16.2 | 2.81 | 8 | 842 | 20.6 | 2.45 | 14 | 849 | ..... | ..... |
| Second generation | 5 | 552 | 14.9 | 2.70 | 8 | 782 | 17.8 | 2.27 | 15 | 817 | ..... | ..... |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | | | Steers fed hegari stover 175 days | | | |
|---|---|---|---|---|---|---|---|---|
| | Animals slaughtered | Final weight of steer | Weight of heads | | Animals slaughtered | Final weight of steer | Weight of heads | |
| | | | Average | Percentage of final weight of steer | | | Average | Percentage of final weight of steer |
| | *Number* | *Pounds* | *Pounds* | | *Number* | *Pounds* | *Pounds* | |
| Hereford, Shorthorn | 24 | 880 | [2] 24.5 | 2.79 | 25 | 863 | 23.7 | 2.75 |
| Brahman-Shorthorn: | | | | | | | | |
| First generation | 24 | 922 | 23.5 | 2.55 | 25 | 918 | 23.2 | 2.53 |

[1] The steers were fed 150 days in 1925–26.
[2] Based on 20 heads, 4 not weighed.

The data pertaining to weights of tongues are given in table 15. When tongue weights are expressed as percentages of the final feed-lot weights, the non-Brahmans have the heavier tongues in every comparison.

TABLE 15.—*Comparison of average weight of tongues of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 3.90 | 0.86 | 5.45 | 0.75 | 5.78 | 0.76 |
| Shorthorn | 3.80 | .75 | 5.41 | .71 | 5.43 | .68 |
| Brahman-Hereford | 3.60 | .65 | 4.95 | .67 | 5.23 | .65 |
| Brahman-Shorthorn: First generation | 3.70 | .65 | 4.97 | .64 | 5.42 | .66 |

1925–26 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 3.45 | 0.88 | 5.30 | 0.78 | 5.33 | 0.74 |
| Shorthorn | 4.12 | .77 | 5.92 | .77 | 5.10 | .66 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 4.05 | .70 | 5.48 | .65 | 5.39 | .64 |
| Second generation | 4.05 | .73 | 5.37 | .69 | 5.50 | .67 |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | Steers fed hegari stover 175 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford, Shorthorn | 6.96 | 0.79 | 6.51 | 0.75 |
| Brahman-Shorthorn: First generation | 6.58 | .71 | 6.65 | .72 |

Brahman cattle differ so markedly from the other beef breeds in alertness, nervous tendencies, and other mental traits, as well as in the shape of the head, that it was thought possible that a significant difference might be found in weight of brain. Accordingly, the brains of the cattle in the first experiment were weighed.

The data in table 16 show the brains of the non-Brahman cattle to be considerably the heavier, but as the heads and also the tongues of the non-Brahmans were likewise heavier, the differences in weight of brains are not considered significant. As the results were of slight commercial importance, the weighing of brains was discontinued after the first year.

TABLE 16.—*Comparison of the average weights of brains of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot, 1924–25 experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 0.794 | 0.175 | 0.914 | 0.125 | 0.831 | 0.109 |
| Shorthorn | .791 | .155 | .715 | .094 | [1].842 | .105 |
| Brahman-Hereford | .800 | .145 | .684 | .093 | .812 | .101 |
| Brahman-Shorthorn | .850 | .149 | .727 | .093 | .805 | .098 |

[1] 1 brain was lost. The data for this lot are based on 15 brains.

## SIZE, WEIGHT, AND THICKNESS OF HIDES

One of the conspicuous characteristics of Brahman cattle is the large quantity of loose skin (dewlap) hanging along the midventral line beginning almost at the muzzle and extending to some distance back of the umbilicus. Because of these large dewlaps and because the Brahmans differed so greatly from Hereford and Shorthorn steers in body conformation, it was thought that the Brahmans might be characterized by relatively larger surface areas than the other steers. Accordingly, the area of each hide was measured shortly after the steers were killed. For measuring these areas a large planimeter similar in principle to those used by draftsmen and cartographers was constructed.[2] This planimeter had wooden arms, each 1.23 meters long and a composition fiber wheel 15.3 centimeters in diameter (fig. 8). The arms proved to be slightly too short for convenience in measuring the very largest hides. Otherwise this planimeter was very satisfactory for the work. It was provided with a revolution counter, and the wheel was graduated to hundredths of a revolution. In operation, the end of the arm bearing the wheel was used to trace the irregular outline of the edge of the hide, while the end of the other arm was held at a point on the floor near the edge of the hide. The revolution counter attached to the wheel shows the area directly, in units determined by the proportions of the instrument, when the moving arm completes its circuit and returns to its starting point. Such units were later converted into square feet. The mathematical principles involved are those of the integral calculus of polar coordinates.

This planimeter was calibrated by measuring with it an area of known size on a floor. When this was measured with the planimeter 11 successive times, a standard deviation of 0.156 square foot was found. That is a probable error for a single measurement of slightly more than one tenth of a square foot. Such ideal conditions were not encountered in measuring the hides. There was opportunity for error as the wheel went up on or came down off the hide, and there was also opportunity for a slight error at times when the hide slipped a little with the wheel.

[2] By E. E. Vezey, Physics Department, Agricultural and Mechanical College of Texas.

In order to estimate the size of the errors actually encountered in measuring the hides, one hide was measured 11 times. The probable error was found to be slightly more than nine tenths of a square foot. On the basis of these findings it was decided to take two measurements of each hide and, if they did not differ by so much as 1 square foot, to use the average of the two as the correct measurement. If, however, the first two measurements differed more than that, additional measurements were made. If the additional measurements showed that one of the first two was very distinctly aberrant it was discarded. If the additional measurements did not show clearly which of the original measurements was aberrant, the average of all measurements made on that hide was used as the correct measurement.

On account of these circumstances the hide areas given are based on averages of from 2 to 5 measurements, and in the authors' judgment

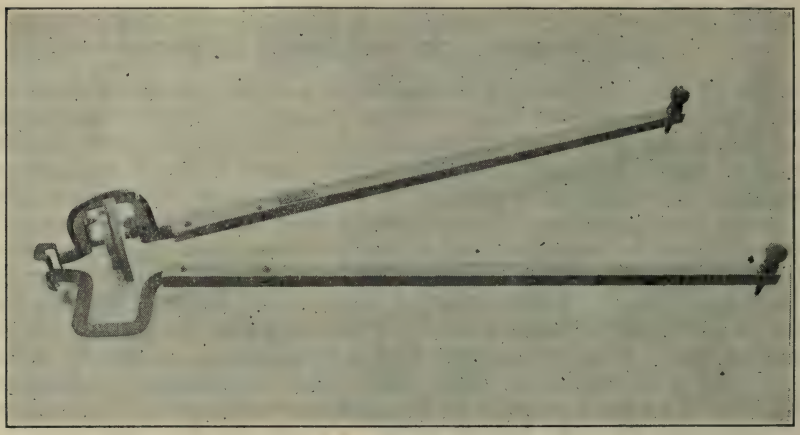

FIGURE 8.—Planimeter used in measuring hide areas.

the probable error of measurement in these averages is less than two thirds of a square foot for each hide. In nearly all groups the variation between steers within the groups far exceeded the error of measurement, and therefore the latter is a very minor element in the difference between group averages. Measurement with the planimeter proved to be very rapid and two men, with a third to make the record, could measure as many as 60 hides in half a day.

The data on hide areas are presented in table 17. In order to eliminate differences which were the direct result of differences in general body size the areas were divided by the two-thirds power of the live weights because in objects geometrically similar in shape the surface varies as the two-thirds power of the volume. Recorded observations (*2*, *3*, *13*) on the weight per unit volume of cattle indicate that this relationship is approximately constant for steers of similar fatness.

TABLE 17.—*Comparison of the average area of hides of the non-Brahman and part-Brahman lots, expressed in square feet and in relation [1] to final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average size | Relation to final weight of steer | Average size | Relation to final weight of steer | Average size | Relation to final weight of steer |
| | *Sq. ft.* | | *Sq. ft.* | | *Sq. ft.* | |
| Hereford | 33.5 | 0.57 | 43.3 | 0.53 | [2] 40.5 | 0.48 |
| Shorthorn | 37.4 | .59 | 41.0 | .49 | 44.5 | .51 |
| Brahman-Hereford | 37.5 | .56 | 43.6 | .53 | 51.0 | .59 |
| Brahman-Shorthorn: First generation | 41.2 | .60 | 43.1 | .51 | 49.6 | .57 |

1925–26 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Average size | Relation to final weight of steer | Average size | Relation to final weight of steer | Average size | Relation to final weight of steer |
| | *Sq. ft.* | | *Sq. ft.* | | *Sq. ft.* | |
| Hereford | [3] 28.8 | 0.57 | 32.0 | 0.41 | 39.6 | 0.49 |
| Shorthorn | 34.1 | .52 | 32.9 | .39 | 39.8 | .47 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 40.8 | .59 | 43.0 | .48 | 46.9 | .52 |
| Second generation | 38.0 | .56 | 37.0 | .44 | 46.0 | .53 |

[1] Figures in this table were obtained by dividing the area of the hides, in square feet, by the two-thirds power of the live weight, in pounds; see text for explanation.
[2] Average of 11 hides.
[3] Average of 4 hides.

The data relating to hide weights are given in table 18 and are expressed both in actual pounds and in percentages of final live-steer weights at feed lot.

The thickness of the uncured hides, including the hair, was studied during the second and third slaughterings of the 1924–25 experiment and the first slaughtering of the 1925–26 experiment. A small machinist's caliper with vernier scale, reading to tenths of a millimeter, was used. At first it was used in the condition in which it was purchased, but the measurements thus taken were erratic owing to the small surfaces of the caliper which came in contact with the hide. To remedy this, copper rivets were soldered to the contact surfaces of the caliper in a manner that did not affect the scale and that made the area of each contact surface about four fifths of a square centimeter. This modified caliper was used on the last 2 of the 3 occasions.

TABLE 18.—*Comparison of average weights of hides of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 39.2 | 8.6 | 59.6 | 8.2 | [1] 64.2 | 8.3 |
| Shorthorn | 41.0 | 8.0 | 51.7 | 6.8 | 54.5 | 6.8 |
| Brahman-Hereford | 50.5 | 9.2 | 61.2 | 8.3 | 63.8 | 8.0 |
| Brahman-Shorthorn: First generation | 52.0 | 9.1 | 58.6 | 7.5 | 59.3 | 7.2 |

1925–26 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | [2] 32.8 | 9.0 | 53.2 | 7.8 | 58.7 | 8.1 |
| Shorthorn | 40.9 | 7.7 | 51.4 | 6.7 | 53.8 | 6.9 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 54.0 | 9.3 | 62.9 | 7.5 | 64.2 | 7.6 |
| Second generation | 46.7 | 8.5 | 56.5 | 7.2 | 64.1 | 7.8 |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | Steers fed hegari stover 175 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford | 65.1 | 7.4 | 62.2 | 7.2 |
| Shorthorn | | | | |
| Brahman-Shorthorn: First generation | 65.3 | 7.1 | 66.1 | 7.2 |

[1] Average of 11 hides.
[2] Average of 4 hides.

The hide was folded flesh side out and the caliper was applied a short distance from the fold. The reading, therefore, was of a double thickness of hide, hair included, and was divided by 2 in obtaining the thickness. The area selected for measurement was on the side approximately midway from back to floor of the chest and about over the fifth to eighth ribs. Special care was used to avoid getting down into the region of the fore flank where the hide was noticeably thinner, or higher on the back where it was noticeably thicker, and to avoid spots where any bits of muscle still adhered to the hide.

Even with the improved caliper the measurements of hide thickness continued to be erratic, being difficult to duplicate and varying from place to place on the same hide.

Since no definite indication of a breed difference in this characteristic was found in the data taken, this feature of the investigation was discontinued. The measurements of hide thickness are not included in this publication.

## WEIGHT OF TAILS

The tails were removed from the carcasses on the killing floor. The tails on the part-Brahman steers were noticeably longer and heavier than those of the non-Brahmans. This larger size also was evident when the weights were divided by the corresponding live weights. However, owing to the small importance of tails in an economic sense and probably also physiologically, the data obtained the first year were deemed to be ample and their further study was discontinued. The data are shown in table 19.

TABLE 19.—*Comparison of the average weights of tails of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot, 1924–25 experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 0.50 | 0.11 | 0.76 | 0.10 | 0.94 | 0.12 |
| Shorthorn | .65 | .13 | .74 | .10 | .85 | .11 |
| Brahman-Hereford | .85 | .15 | .83 | .11 | 1.05 | .13 |
| Brahman-Shorthorn | .80 | .14 | .86 | .11 | .99 | .12 |

## WEIGHT OF LEG BONES AND FEET

Early in the skinning process, the hide was removed from the legs. The leg bones were then unjointed at the knee and hock joints and were separated from the carcass. The bones thus removed still had the hoofs attached, although the dewclaws were removed before the hide was skinned off. Practically no muscle tissue w sa present, but there were tendons and other connective tissue and small quantities of other tissues such as blood vessels and nerves. The leg bones were weighed just as they were taken from the steers and the results for the various lots of steers appear in table 20.

TABLE 20.—*Comparison of the average weights of leg bones, including feet, of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 8.90 | 1.96 | 12.03 | 1.65 | 12.91 | 1.69 |
| Shorthorn | 10.20 | 2.00 | 12.59 | 1.65 | 13.19 | 1.64 |
| Brahman-Hereford | 10.00 | 1.81 | 12.16 | 1.65 | 13.42 | 1.68 |
| Brahman-Shorthorn: First generation | 11.15 | 1.96 | 12.78 | 1.64 | 13.94 | 1.70 |

1925–26 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 8.20 | 2.09 | 10.68 | 1.57 | 11.67 | 1.62 |
| Shorthorn | 10.44 | 1.96 | 13.11 | 1.72 | 12.00 | 1.54 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 11.70 | 2.02 | 13.10 | 1.56 | 13.46 | 1.59 |
| Second generation | 11.25 | 2.04 | 12.89 | 1.65 | 13.44 | 1.64 |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay | | Steers fed hegari stover | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford, Shorthorn | 14.96 | 1.70 | 14.03 | 1.63 |
| Brahman-Shorthorn: First generation | 15.11 | 1.64 | [1] 15.10 | 1.65 |

[1] All legs of 5 steers and 1 leg of another in this group of 24 steers not weighed.

## WEIGHTS OF HEARTS AND LUNGS

The hearts were weighed just as they were removed from the pluck. They had been cut open and all blood was removed. Data pertaining to the weights of the hearts are shown in table 21.

The lungs, including the tracheae, were weighed immediately after they were taken from the steers and after the hearts had been removed from them. No trimming of the lungs and tracheae was done. The data are shown in table 22. Since the first year's results seemed to show rather clearly that there was little prospect of finding a breed difference in lung-and-trachea weight, no data on this point were collected during the second and third years.

TABLE 21.—*Comparison of average weights of untrimmed hearts, as removed from the steers, of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 1.85 | 0.41 | 2.54 | 0.35 | 3.21 | 0.42 |
| Shorthorn | 2.00 | .39 | 2.91 | .38 | 3.22 | .40 |
| Brahman-Hereford | 2.00 | .36 | 2.97 | .40 | 3.09 | .39 |
| Brahman-Shorthorn: First generation | 2.35 | .41 | 3.07 | .39 | 3.51 | .43 |

1925–26 EXPERIMENT

| | | | | | | |
|---|---|---|---|---|---|---|
| Hereford | 1.80 | 0.46 | 2.53 | 0.37 | | |
| Shorthorn | 2.12 | .40 | 3.05 | .40 | | |
| Brahman-Shorthorn: | | | | | | |
| First generation | 2.25 | .39 | 3.20 | .38 | | |
| Second generation | 2.15 | .39 | 3.07 | .39 | | |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | Steers fed hegari stover 175 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford, Shorthorn | [1] 3.61 | 0.42 | [2] 3.52 | 0.40 |
| Brahman-Shorthorn: First generation | [3] 3.85 | .42 | 3.93 | .43 |

[1] Average of 14 hearts. [2] Average of 19 hearts. [3] Average of 17 hearts.

TABLE 22.—*Comparison of the average combined weights of lungs and tracheae of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot, 1924–25 experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 4.25 | 0.93 | 6.56 | 0.90 | 8.04 | 1.05 |
| Shorthorn | 4.70 | .92 | 6.85 | .90 | 7.95 | .99 |
| Brahman-Hereford | 4.70 | .85 | 6.84 | .93 | 7.73 | .97 |
| Brahman-Shorthorn | 5.10 | .89 | 7.06 | .90 | 8.32 | 1.01 |

## WEIGHTS OF LIVERS, SPLEENS, AND SWEETBREADS

The livers were weighed as taken from the steers with only the trimming incidental to removing the gall bladders. The data pertaining to liver weights are given in table 23. As the first year's data showed no indication of a real difference between the part-Brahman and non-Brahman steers with respect to weight of livers, no further data were collected.

TABLE 23.—*Comparison of the average weights of the livers of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot, 1924–25 experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 4.85 | 1.07 | 8.37 | 1.15 | 9.92 | 1.30 |
| Shorthorn | 5.75 | 1.13 | 9.29 | 1.22 | 10.96 | 1.36 |
| Brahman-Hereford | 5.80 | 1.05 | 8.64 | 1.17 | 9.95 | 1.24 |
| Brahman-Shorthorn | 6.40 | 1.12 | 9.83 | 1.26 | 10.36 | 1.26 |

Spleens were weighed only during the first year since there seemed to be no evidence of a breed difference. The data are shown in table 24.

TABLE 24.—*Comparison of the weights of spleens of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot, 1924–25 experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 0.95 | 0.21 | 1.34 | 0.18 | 1.59 | 0.21 |
| Shorthorn | [1] 1.45 | .28 | 1.56 | .20 | [2] 1.96 | .24 |
| Brahman-Hereford | 1.25 | .23 | 1.50 | .20 | 1.86 | .23 |
| Brahman-Shorthorn | 1.15 | .20 | 1.52 | .19 | 2.01 | .24 |

[1] This included 1 very heavy spleen weighing 2¾ pounds. There was no reason other than its very abnormal size for regarding this spleen as abnormal and consequently it was included in the calculations.
[2] The spleen from 1 steer was lost. The data for this group are based on 15 steers.

An attempt was made to weigh the sweetbreads (thymus) but difficulty was encountered in separating them neatly from the other tissues in the short time available during the procedure on the killing floor. Also the size of the sweetbreads was so much influenced by the age of the steers that there seemed to be little chance of determining breed differences even if such existed. After the second slaughtering the weighing of these organs was dropped from the procedure. The data are given in table 25.

TABLE 25.—*Comparison of the average weights of commercial sweetbreads (thymus) of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of final live-steer weights at feed lot, 1924–25 experiment*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford | 1. 40 | 0. 31 | 0. 49 | 0. 07 |
| Shorthorn | 1. 15 | . 22 | . 44 | . 06 |
| Brahman-Hereford | 1. 25 | . 23 | . 37 | . 05 |
| Brahman-Shorthorn | 1. 25 | . 22 | . 42 | . 05 |

## WEIGHT OF STOMACHS AND WEIGHT AND LENGTH OF INTESTINES

The problem of making accurate comparisons of the stomachs of cattle is apparent to all persons familiar with the anatomy of ruminants. In a study of this kind the capacity of the stomachs is more important than the weight of the tissues. The weight of the full stomachs and their contents depends to a large extent on the variable quantities of feed and water contained which, incidentally, are much influenced by the length of time between the last feeding and slaughter.

A natural solution to the problem of making accurate comparisons of the stomachs of cattle would be some such method as measuring the capacities of the stomachs directly by emptying them, then filling them with water under water (to equalize pressure), and weighing or measuring the water thus contained. But such a procedure was impracticable for use on bovine stomachs at commercial packing plants. Accordingly the stomachs were weighed full, all four compartments together, just as they were taken from the steers. The weight of the weasand (esophagus) also was included in the weight of the stomach. To avoid delay, no trimming of fat, spleen, or other attached small parts was attempted. Data obtained on weights of stomachs and contents are given in table 26.

Consideration of weights of full intestines as measures of intestinal capacity involves difficulties similar to those mentioned in connection with weights of stomachs. The intestines (including attached fat and the pancreas) were weighed on the killing floor. The data obtained are shown in table 27. The intestines were also emptied and measured for length on two slaughtering occasions.

TABLE 26.—*Comparison of the average weights of the full stomachs of the non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 52.8 | 11.6 | 68.2 | 9.3 | 87.3 | 11.4 |
| Shorthorn | 65.0 | 12.8 | 85.1 | 11.2 | 104.2 | 13.0 |
| Brahman-Hereford | 56.5 | 10.2 | 59.9 | 8.2 | 68.3 | 8.5 |
| Brahman-Shorthorn: First generation | 74.9 | 13.1 | 63.1 | 8.1 | 64.6 | 7.9 |

1925–26 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 46.2 | 11.8 | 60.3 | 8.9 | 47.1 | 6.5 |
| Shorthorn | 57.0 | 10.7 | 72.2 | 9.4 | 46.7 | 6.0 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 50.8 | 8.8 | 63.8 | 7.6 | 49.6 | 5.8 |
| Second generation | 51.2 | 9.3 | 62.6 | 8.0 | 41.4 | 5.1 |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | Steers fed hegari stover 175 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford, Shorthorn | 90.8 | 10.3 | 97.3 | 11.3 |
| Brahman-Shorthorn: First generation | 84.2 | 9.1 | 89.0 | 9.7 |

TABLE 27.—*Comparison of the average weights of full intestines of non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weight at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 22.0 | 4.8 | [1] 34.6 | 4.8 | 36.3 | 4.8 |
| Shorthorn | 23.8 | 4.7 | 34.5 | 4.5 | 40.7 | 5.1 |
| Brahman-Hereford | 22.2 | 4.0 | 31.0 | 4.2 | 32.9 | 4.1 |
| Brahman-Shorthorn: First generation | 22.5 | 3.9 | 27.7 | 3.6 | 33.1 | 4.0 |

1925–26 EXPERIMENT

| | | | | | | |
|---|---|---|---|---|---|---|
| Hereford | 22.1 | 5.6 | 34.1 | 5.0 | ---------- | ---------- |
| Shorthorn | 23.0 | 4.3 | 34.3 | 4.5 | ---------- | ---------- |
| Brahman-Shorthorn: | | | | | | |
| First generation | 23.4 | 4.0 | 31.9 | 3.8 | ---------- | ---------- |
| Second generation | 24.1 | 4.4 | 30.9 | 3.9 | ---------- | ---------- |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | Steers fed hegari stover 175 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford, Shorthorn | 40.6 | 4.6 | 41.3 | 4.8 |
| Brahman-Shorthorn: First generation | 38.8 | 4.2 | 38.0 | 4.1 |

[1] Intestines from only 6 animals included.

TABLE 28.—*Comparison of the average length of intestines of the experimental cattle, 1924–25*

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | |
|---|---|---|---|---|
| | Small intestines | Large intestines | Small intestines | Large intestines |
| | *Feet* | *Feet* | *Feet* | *Feet* |
| Hereford | 98.4 | 20.9 | 105.9 | 20.4 |
| Shorthorn | 99.4 | 21.6 | 115.5 | 21.5 |
| Brahman-Hereford | 97.1 | 21.4 | 107.6 | 22.5 |
| Brahman-Shorthorn | 98.9 | 21.6 | 107.6 | 21.4 |

## WEIGHTS OF CAUL, RUFFLE, AND PAUNCH FATS

Comparisons of the caul, ruffle, and paunch fats were thought to be of value in interpreting differences in gains, dressing percentages, and apparent efficiency in the use of feed. Accordingly, observations were made of these internal fats. Caul fats were weighed on all seven slaughtering occasions. The data are given in table 29.

TABLE 29.—*Comparison of the average weights of caul fat of non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weight at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 2.95 | 0.65 | 5.25 | 0.72 | 6.67 | 0.87 |
| Shorthorn | 2.20 | .43 | 4.70 | .62 | 7.77 | .97 |
| Brahman-Hereford | 2.35 | .43 | 5.53 | .75 | 8.64 | 1.08 |
| Brahman-Shorthorn: First generation | 2.70 | .47 | 5.19 | .67 | 7.90 | .96 |

1925–26 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 2.20 | 0.56 | 6.62 | 0.98 | 6.68 | 0.93 |
| Shorthorn | 2.69 | .50 | 8.04 | 1.05 | 10.77 | 1.39 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 1.30 | .22 | 6.87 | .82 | 9.66 | 1.14 |
| Second generation | 3.40 | .62 | 9.23 | 1.18 | 9.75 | 1.19 |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | Steers fed hegari stover 175 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford, Shorthorn | 7.60 | 0.86 | 6.54 | 0.76 |
| Brahman-Shorthorn: First generation | 8.72 | .95 | 9.80 | 1.07 |

Ruffle fats were weighed on all except the first slaughtering occasion. The data are given in table 30.

TABLE 30.—*Comparison of the average weights of ruffle fat of non-Brahman and part-Brahman lots, expressed in pounds and as percentages of the final live-steer weights at feed lot*

1924–25 EXPERIMENT

| Breeding | Steers fed 120 days | | Steers fed 179 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford | 5.59 | 0.76 | 5.56 | 0.73 |
| Shorthorn | 5.07 | .67 | 5.83 | .73 |
| Brahman-Hereford | 5.51 | .75 | 5.46 | .68 |
| Brahman-Shorthorn: First generation | 4.70 | .60 | 4.58 | .56 |

1925–26 EXPERIMENT

| Breeding | Steers at beginning of experiment | | Steers fed 120 days | | Steers fed 150 days | |
|---|---|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | | *Pounds* | |
| Hereford | 2.10 | 0.54 | 6.02 | 0.89 | 7.07 | 0.98 |
| Shorthorn | 2.31 | .43 | 6.15 | .80 | 9.20 | 1.18 |
| Brahman-Shorthorn: | | | | | | |
| First generation | 1.70 | .29 | 5.62 | .67 | 7.64 | .90 |
| Second generation | 2.75 | .50 | 5.47 | .70 | 6.73 | .82 |

1926–27 EXPERIMENT

| Breeding | Steers fed Rhodes-grass hay 175 days | | Steers fed hegari stover 175 days | |
|---|---|---|---|---|
| | Average weight | Percentage of final weight of steer | Average weight | Percentage of final weight of steer |
| | *Pounds* | | *Pounds* | |
| Hereford, Shorthorn | 6.28 | 0.71 | [1] 5.41 | 0.63 |
| Brahman-Shorthorn: First generation | 6.80 | .74 | [1] 6.14 | .67 |

[1] Based on 24 ruffles, 1 not weighed.

Paunch fat, which is trimmed from the outside of the stomachs, was weighed on two slaughterings in the first experiment. The accuracy of this weight was affected considerably by the care used in trimming off small pieces of this fat. Accordingly, paunch fat was not weighed after the end of the first experiment and the data obtained, which incidentally showed no consistent differences, are not presented.

## DISCUSSION OF DATA

Table 31 shows the statistically significant differences in the percentages which the weights of the various organs or parts constituted of the final feed-lot weights of part Brahmans as compared with non-Brahmans. These figures were obtained by averaging all

the comparable differences, giving equal weight to each such difference between lots. Connected with these differences and partially included in them were larger hide areas on the part Brahmans but heavier stomach and intestine contents in the non-Brahmans.

TABLE 31.—*Comparison of non-Brahman and part-Brahman cattle with respect to statistically significant differences in weights of various organs and parts*

| Organ or part | Average excess percentage of organ or part based on live weight at feed lot | |
|---|---|---|
| | Part Brahmans | Non-Brahmans |
| Head (not including tongue) | | 0.145 |
| Tongue | | .085 |
| Hide | 0.280 | |
| Tail | .017 | |
| Full stomachs | | 1.860 |
| Full intestines | | .744 |
| Warm carcass | 2.230 | |

No statistically significant differences were found in hide thickness, intestine length, or in weight of heart, lungs, spleen, thymus, brain, leg bones and feet, or caul, ruffle, and paunch fat. The matter of hide thickness may deserve reexamination when a more satisfactory technic is developed for measuring hide thickness directly. However, not only did the direct measurements by calipers fail to reveal breed differences between part Brahmans and non-Brahmans in these experiments, but also the weights of the hides per square foot of area were not significantly different. Therefore the writers have considerable confidence in the general conclusion that breed differences in hide thickness are unimportant. There seems to be no definite literature on the normal variation in hide thickness.

Of the differences found, that in hide area is of little economic importance directly but may be of considerable physiological importance and may help explain why cattle of Brahman breeding thrive in hot climates. The larger area provides more radiating surface for disposing of the surplus heat produced by muscular exertion, digestion, and other metabolic activities.

The differences in weights of heads, tongues, and tails, although significant statistically, are too small to be important economically. The difference in carcass yield is very important economically and has long been recognized in a general way by the packers and commissionmen who are acustomed to cattle of Brahman breeding.

The differences in weight and capacity of the digestive tract go far toward explaining the higher carcass yield of the Brahmans. These differences apparently influence the feeding habits of the cattle and perhaps even affect digestive efficiency under certain conditions. Throughout these experiments the Brahmans had a distinct tendency to eat many times during the day but not a large quantity at any one time. The smaller capacity of their digestive tracts offers a plausible explanation for this peculiarity.

Weights of the same stomachs full at first and then emptied lead to the conclusion that the breed difference is primarily one of capacity rather than in the amounts of actual tissue present. It is frequently said that a large digestive tract is essential for large gains. The data of these experiments offered a chance partially to test this by comput-

ing the average intra-lot correlations between previous gain and full-stomach weights and full-intestine weights. The correlation between previous gain and full-stomach weights was +0.36 (279 degrees of freedom). That between previous gain and full-intestine weights was +0.53 (235 degrees of freedom). The correlation between full-stomach and full-intestine weights was +0.52 (235 degrees of freedom). These correlations indicate a distinct but far from perfect correlation between previous gain and capacity of digestive tract. These relations are complicated, however, by the fact that weights of stomachs and intestines include part of the observed gain in live weight and by the fact that weights of full stomachs and intestines are not perfect measures of capacity of the digestive tract.

The full intestines of the non-Brahmans constituted, according to the average of 11 differences between comparable lots, 0.74 percent more of the live weight of non-Brahmans than of the part-Brahmans. This difference is both statistically significant and commercially important. It parallels the difference in stomachs. These analyses of the data indicate a general difference in digestive tract rather than special differences in 1 or 2 digestive organs.

The percentages which some organs or parts constitute of the live weight depend much upon the steer's age and degree of fatness. Thus the thymus of the growing steer decreases rapidly even in absolute weight. It seems unimportant after weaning time. Head and leg bones, and in fact bony parts in general, increase in absolute weight during fattening but decrease as percentages of the live weight. On the contrary the heart remains almost a constant percentage of the live weight during fattening and the lungs actually increase faster than the live weight does. This observation suggests that a fat steer has need for more blood and oxygen supply per unit of actual living protoplasm than the thin steer does. The liver also becomes a larger percentage of the live weight as steers grow older and fatten.

During the first year there was a statistically significant difference between Herefords and Shorthorns in weight of liver but these groups had come from widely separated pastures and the difference may as well have been the result of pre-experimental treatment as that of genuine breed differences. This point was not followed further and is reported here only to record a clue for further attention at some future time.

Brahman characteristics which were completely recessive in inheritance, if there were any such, could scarcely have been detected in these experiments. Only the Shorthorn-Brahmans fed the second and third years could have shown such characteristics. Even here they would have appeared in only a few individuals and would have been obscured by the method of analysis which was largely a comparison of group averages. Doubtless the total number of genetic differences between Brahman and Hereford or Shorthorn cattle is enormously greater than the few indicated by the crosses studied in this experiment.

It is not surprising that only small differences in weights of organs and parts were found, especially since the experimental cattle were all of beef type. Swett, Graves, and Miller (*6*), who compared a highly specialized beef cow and a highly specialized dairy cow, report only small anatomical and structural differences. Though the external form of the two cows differed greatly, those investigators

found that "in weight and size of internal organs the differences were not sufficiently great to indicate significant differences in function."

### ORGANS AND PARTS NOT RECOVERED AT SLAUGHTERING TIME

The total weight of the organs and parts weighed at slaughtering time of course was less than the live weight at the feed lot. Part of the weight not accounted for was the shrinkage during shipment. That ranged from as low as 3 percent for one shipment to about 7.5 percent for the three shipments during the second year. No doubt there was additional shrinkage between the time when the steers were weighed across the stockyard scales and the time they were actually killed. That interval was usually about 20 hours although it ranged from 2 to more than 30 hours. During this time the steers had access to water but not to feed.

No attempt was made to weigh the blood, which other studies have shown to be about 4 or 5 percent of the live weight. Even on the first two slaughtering occasions some of the smaller organs, such as the urinary bladder, were not weighed. After the first year, livers and lungs were omitted. At the sixth slaughtering occasion it was not feasible to weigh the heads nor any part of the full intestines except the ruffle fat. However, the procedure was always the same for all groups slaughtered on the same occasion. Differences between groups slaughtered at the same time are, therefore, comparable.

The percentage of the feed-lot weight obtained when the steers were weighed over the stockyard scales but not recovered on the killing floor varied at different slaughterings from 7.0 to 9.9 percent except on the one occasion when it was not possible to weigh the heads or the full intestines. Since the blood alone must have been about half of the weight unaccounted for, it is felt certain that there cannot have been an important difference in the weight of the parts not recovered.

The observed differences between part-Brahmans and non-Brahmans, both in shrinkage from feed lot to market and in shrinkage from the stockyard scales to the killing floor, are so small and so inconsistent ($P$ is above 0.70 in both cases) that neither difference can be regarded as even suggesting significance. According to the data obtained, the stomachs and intestines of the Brahmans are distinctly smaller than those of the non-Brahmans even when the cattle are normally on pasture or in feed lots.

### INDIVIDUAL VARIATION IN WEIGHTS OF ORGANS

Aside from fragmentary references no literature was found on the amount of variation normally to be expected in the weights or sizes of various organs and parts. To report such information for the use of future investigators, table 32 has been prepared. In it are shown the averages of the intra-lot standard deviations for most of the items on which slaughter data were obtained. This information is shown separately for the feeder calves and for the fat steers because the proportions of some of these organs or parts change rapidly with fattening or between the ages involved. Some organs or parts were weighed individually at every slaughtering occasion but others were weighed on only a few. Still others were sometimes weighed in

groups, thus making possible the averages which were the main object of the investigation but not providing any measure of the variation within the groups. Hence the amount of evidence on which these average standard deviations are based varies from item to item. For this reason table 32 shows the number of degrees of freedom, that is, the amount of information, on which each average standard deviation is based. The $n-1$ formula was used in computing these standard deviations. Sheppard's correction was not used.

TABLE 32.—*Intra-lot variation in weights or sizes of various parts or organs*

| Part or organ | Feeder calves [1] | | Fattened steers [2] | |
|---|---|---|---|---|
| | Degrees of freedom | Average intra-lot standard deviation | Degrees of freedom | Average intra-lot standard deviation |
| | *Number* | | *Number* | |
| Head without tongue, pounds | 31 | 1.91 | 117 | 1.37 |
| Tongue, do | 31 | .63 | 117 | .53 |
| Hide area, square feet | 30 | 4.22 | 161 | 3.28 |
| Hide weight, pounds | 30 | 7.10 | 255 | 6.82 |
| Leg bones and feet, do | 31 | 1.11 | 117 | .90 |
| Untrimmed hearts, do | 31 | .32 | 164 | .36 |
| Lungs and trachea, do | 16 | .39 | 90 | .77 |
| Liver, do | 16 | .58 | 90 | 1.24 |
| Spleen, do | 16 | .44 | 89 | .32 |
| Thymus, do | 16 | .22 | 28 | .12 |
| Brain, do | 16 | .06 | 89 | .08 |
| Tail, do | | | 90 | .16 |
| Full stomachs, do | 31 | 11.14 | 261 | 12.65 |
| Full intestines, do | 31 | 3.23 | 209 | 5.51 |
| Length of small intestine, feet | 16 | 6.37 | 28 | 11.15 |
| Length of large intestine, do | 16 | 1.31 | 28 | 2.61 |
| Caul fat, pounds | 31 | .86 | 254 | 2.53 |
| Ruffle fat, do | 15 | .54 | 259 | 1.51 |
| Paunch fat, do | | | 90 | .92 |

[1] There were 39 feeder calves in 8 groups. The average live weights of those groups at the ranch ranged from 392 to 578 pounds. The average for all the calves was 517 pounds.

[2] There were 281 fattened steers killed in 20 groups after 120 to 179 days on full feed. The average live weights of these groups at the ranch ranged from 678 to 922 pounds. The average for all the steers was 819 pounds.

So far as these various items were correlated individually with differences in live weight, the standard deviation actually found is larger than it would have been if the steers within each group had been more nearly identical in live weight than these actually were. Conversely, in any future experiment where the lots of steers are less uniform than these were, the standard deviations may be expected to be somewhat larger than the ones given in table 32. For example, the feeder calves killed at the beginning of the second experiment were selected to include both the large and the small individuals of their corresponding lots, in order to give representative averages for the feeder steers and yet to leave more uniform groups for the subsequent fattening. This selection of extremes to be slaughtered in the feeder group is largely responsible for the standard deviation for heads, hides, and leg bones being larger within the lots of feeder calves than within the lots of fattened steers.

No breed differences were found in the variability within lots but such differences would scarcely be expected since all the animals were either high grades or first crosses except the second-generation animals of the second and third years. These latter would theoretically have been expected to show more variability than the first

generation or high grades but the conditions of the experiment were such that significant differences of this kind could hardly have been found unless they were very extreme, especially since these double-cross animals were from selected first-cross parents.

The information in table 32 should help anyone planning the collection of similar data to decide what degree of precision would be desirable in weighing or measuring each item. A good general rule is that if the class interval is no larger than one fourth of the standard deviation, little information is gained by making the observations with still greater precision. For example, the standard deviation of the individual hearts was practically one third of a pound. Accordingly it would appear that anyone planning to study individual weights of hearts would lose a little information by weighing them only to the nearest tenth of a pound but that little would be gained by weighing them to a degree of precision farther than to the nearest sixteenth or to the nearest twentieth of a pound. On the other hand there would be little object in weighing hides any closer than to the nearest pound or in weighing the full stomachs closer than to the nearest 2 or 3 pounds. At the other extreme, anyone

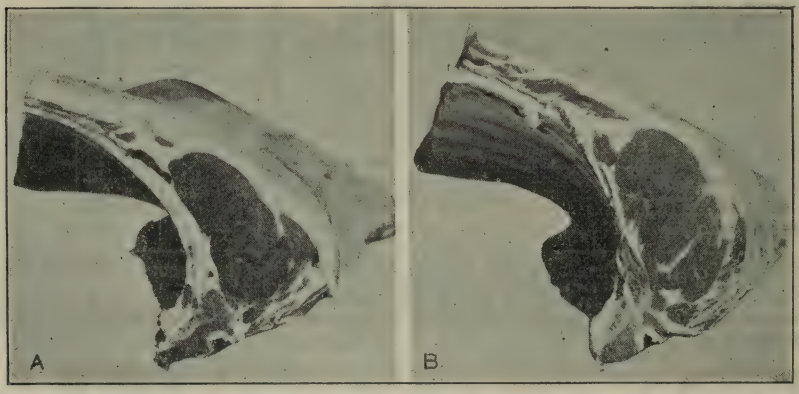


FIGURE 9.—Comparison of typical ribs from steers fattened 179 days: *A*, Rib from a Hereford carcass; *B*, rib from a Brahman-Hereford, 1924–25.

studying the individual weights of brains of cattle would need to count on weighing them at least to the nearest fiftieth of a pound and preferably to the nearest hundredth of a pound in order to utilize nearly all the information which is in the data.

## COMPARISONS OF QUALITY AND PALATABILITY OF MEAT

### PHYSICAL COMPARISONS OF CARCASSES AND THEIR PRINCIPAL DIVISIONS, 1924–25

In the first experiment, 1924–25, sides of representative carcasses from each lot were divided into wholesale cuts and these cuts were separated for purposes of comparison into bone, fat, and lean, under the direct supervision of the authors. This work was done in the packing plant at Fort Worth, where the cattle were slaughtered. The percentages of bone, fat, and lean and of various divisions of the hind quarters and fore quarters were determined, as shown in table 33. A comparison of two typical ribs is shown in figure 9.

TABLE 33.—*Comparison of bone, fat, and lean, and wholesale cuts, expressed as percentage of carcass, 1924–25*

| Feeding period and breeding of steers | Carcasses | Carcass | | | Hind quarters | | | | | | Fore quarters | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Bone | Fat | Lean | Round | Rump | Loin | Flank | Kidney | Total | Ribs | Chuck and neck | Plate and brisket | Fore shank | Total |
| At beginning of experiment: | *No.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Hereford | 2 | 25. 26 | 4. 90 | 69. 84 | 23. 60 | 4. 28 | 17. 57 | 3. 09 | 0. 78 | 49. 32 | 9. 78 | 25. 14 | 10. 27 | 5. 49 | 50. 68 |
| Shorthorn | 2 | 26. 70 | 3. 51 | 69. 79 | 23. 33 | 5. 00 | 16. 55 | 4. 13 | . 76 | 49. 77 | 9. 45 | 24. 55 | 10. 23 | 6. 00 | 50. 23 |
| Brahman-Hereford | 2 | 23. 70 | 3. 88 | 72. 42 | 22. 72 | 5. 07 | 16. 54 | 3. 90 | . 69 | 48. 92 | 9. 27 | 26. 44 | 9. 77 | 5. 60 | 51. 08 |
| Brahman-Shorthorn | 2 | 24. 16 | 3. 47 | 72. 37 | [1] 29. 70 | | 15. 24 | 2. 53 | . 73 | 48. 20 | 9. 75 | 25. 90 | 10. 85 | 5. 30 | 51. 80 |
| Fed 120 days: | | | | | | | | | | | | | | | |
| Hereford | 1 | 18. 97 | 9. 12 | 71. 91 | 21. 38 | 5. 23 | 18. 26 | 2. 94 | 1. 16 | 48. 97 | 8. 35 | 27. 99 | 11. 14 | 3. 55 | 51. 03 |
| Shorthorn | 1 | 19. 19 | 7. 97 | 72. 84 | 21. 61 | 4. 16 | 16. 36 | 3. 60 | 1. 39 | 47. 12 | 9. 95 | 27. 87 | 10. 72 | 4. 34 | 52. 88 |
| Brahman-Hereford | 1 | 18. 70 | 6. 36 | 74. 94 | 22. 42 | 4. 61 | 16. 26 | 3. 15 | 1. 52 | 47. 96 | 9. 25 | 26. 73 | 11. 54 | 4. 52 | 52. 04 |
| Brahman-Shorthorn | 1 | 19. 50 | 7. 16 | 73. 74 | 23. 08 | 4. 74 | 17. 70 | 3. 08 | 1. 07 | 49. 67 | 9. 23 | 24. 92 | 11. 45 | 4. 73 | 50. 33 |
| Fed 179 days: | | | | | | | | | | | | | | | |
| Hereford | 1 | 18. 16 | 10. 43 | 71. 41 | 20. 51 | 3. 35 | 20. 25 | 3. 53 | 1. 94 | 49. 58 | 12. 37 | 22. 98 | 11. 49 | 3. 58 | 50. 42 |
| Shorthorn | 1 | 18. 68 | 10. 82 | 70. 50 | 20. 59 | 4. 43 | 19. 22 | 3. 54 | 1. 37 | 49. 15 | 12. 22 | 21. 70 | 12. 93 | 4. 00 | 50. 85 |
| Brahman-Hereford | 1 | 16. 34 | 11. 24 | 72. 42 | 20. 10 | 3. 54 | 19. 21 | 4. 46 | 1. 94 | 49. 25 | 11. 76 | 23. 67 | 11. 93 | 3. 39 | 50. 75 |
| Brahman-Shorthorn | 1 | 19. 24 | 7. 53 | 73. 23 | 23. 70 | 3. 82 | 17. 59 | 3. 16 | 1. 57 | 49. 84 | 10. 34 | 24. 03 | 11. 30 | 4. 49 | 50. 16 |
| Average: | | | | | | | | | | | | | | | |
| Non-Brahman | ----- | 21. 16 | 7. 79 | 71. 05 | 21. 84 | 4. 41 | 18. 04 | 3. 47 | 1. 23 | 48. 98 | 10. 35 | 25. 04 | 11. 13 | 4. 49 | 51. 02 |
| Part Brahman | ----- | 20. 27 | 6. 61 | 73. 19 | 22. 40 | 4. 36 | 17. 09 | 3. 38 | 1. 25 | 48. 97 | 9. 93 | 25. 28 | 11. 14 | 4. 67 | 51. 03 |

[1] Round and rump combined.

## CATTLE AND CARCASS GRADING AND LABORATORY STUDIES OF MEAT, 1925–27

After research work under the national cooperative meat project was inaugurated, the meat studies in the 1925–26 and 1926–27 experiments were associated with that project. During those years the cattle and carcasses were graded, and rib samples from typical steers in the various lots were forwarded to the laboratories of the United States Department of Agriculture at Beltsville, Md., and Washington, D.C., for study, including palatability tests of cooked meat.

### GRADING OF CATTLE AND CARCASSES, 1925–27

The cattle and carcasses were graded individually by a committee composed of three members, representing the cooperating agencies. Each member graded each animal and carcass independently, and the average of the three gradings was taken as the official grade.

A grading chart was used to provide a means of assigning numerical values to all parts and characteristics of the animals and carcasses. The total of the values for an animal regarded as perfect would have been 100 points. The values assigned to the different items on the chart were based on 4-year average prices (1921–24) of wholesale beef cuts and carcasses, together with average weights of cuts expressed in percentages of weight. Thus the grading charts furnished a measure of the value of the steers and beef cuts on a practical market basis. The feeder grades used and the range of values representing each were: (1) Selected, 90+ to 100; (2) choice, 80+ to 90; (3) good, 70+ to 80; (4) medium, 60+ to 70; (5) common, 50+ to 60; and (6) inferior, 40+ to 50.

At the close of each feeding period the slaughter cattle and their respective carcasses were graded individually by the committee in a manner similar to that employed in grading the feeders. The slaughter-cattle and beef-carcass grades used and the range of values represent-

ing each were as follows: (1) Prime, 90+ to 100; (2) choice, 80+ to 90; (3) good, 70+ to 80; (4) medium, 60+ to 70; (5) common, 50+ to 60; (6) cutter, 40+ to 50; and (7) low cutter, 30+ to 40. Variations within grades were designated by "high", "middle", or "low", thereby providing a greater number of comparative terms. Table 34 shows the quality of the cattle, as expressed numerically under the grading system, for the 2 years during which grading was done. Table 35 provides a summary of the data for a more direct comparison of Herefords and Shorthorns with the Brahman crossbreds.

TABLE 34.—*Averages and ranges of numerical grades of feeder-cattle, slaughter-cattle, and beef-carcass grades*

| Year, feeding period, and breeding of steers | Steers | Feeder grade | | Slaughter grade | | Carcass grade | |
|---|---|---|---|---|---|---|---|
| | | Range | Average | Range | Average | Range | Average |
| 1925–26 | *Number* | | | | | | |
| At beginning of experiment: | | | | | | | |
| Hereford | 5 | | | 71. 2–75. 8 | 74. 0 | 63. 2–68. 2 | 65. 9 |
| Shorthorn | 4 | | | 70. 6–77. 5 | 74. 1 | 59. 6–67. 3 | 64. 9 |
| Brahman-Shorthorn: | | | | | | | |
| First generation | 5 | | | 67. 5–72. 3 | 70. 0 | 60. 4–65. 8 | 63. 3 |
| Second generation | 5 | | | 66. 9–76. 9 | 70. 3 | 64. 2–71. 2 | 67. 9 |
| Fed 120 days: | | | | | | | |
| Hereford | 6 | 78. 9–91. 5 | 83. 6 | 74. 0–83. 4 | 78. 8 | 69. 2–78. 9 | 72. 4 |
| Shorthorn | 9 | 75. 5–90. 0 | 84. 5 | 71. 1–80. 4 | 75. 0 | 71. 2–78. 8 | 73. 3 |
| Brahman-Shorthorn: | | | | | | | |
| First generation | 8 | 64. 1–75. 8 | 69. 5 | 62. 9–78. 1 | 71. 3 | 65. 5–74. 6 | 71. 6 |
| Second generation | 8 | 65. 9–78. 4 | 71. 9 | 66. 7–76. 2 | 70. 4 | 67. 5–73. 5 | 70. 6 |
| Fed 150 days: | | | | | | | |
| Hereford | 15 | 76. 5–91. 6 | 82. 2 | 66. 5–73. 5 | 69. 0 | 66. 1–75. 6 | 70. 1 |
| Shorthorn | 10 | 76. 1–89. 4 | 81. 2 | 61. 5–74. 7 | 68. 9 | 65. 0–75. 9 | 71. 2 |
| Brahman-Shorthorn: | | | | | | | |
| First generation | 13 | 64. 3–71. 3 | 68. 2 | 60. 9–73. 6 | 67. 3 | 66. 2–72. 0 | 69. 4 |
| Second generation | 15 | 66. 3–76. 8 | 70. 2 | 59. 9–72. 7 | 66. 5 | 61. 4–76. 8 | 69. 9 |
| 1926–27 | | | | | | | |
| Fed 175 days: | | | | | | | |
| Hereford and Shorthorn (fed Rhodes-grass hay) | 24 | 61. 4–81. 5 | 72. 0 | 62. 0–80. 5 | 70. 1 | 59. 2–74. 6 | 66. 0 |
| Hereford and Shorthorn (fed hegari stover) | 25 | 67. 1–78. 5 | 71. 4 | 57. 1–77. 5 | 68. 8 | 57. 7–70. 1 | 64. 1 |
| Brahman-Shorthorn (fed Rhodes-grass hay) | 24 | 64. 6–73. 0 | 67. 7 | 61. 5–75. 9 | 69. 1 | 57. 9–71. 3 | 66. 2 |
| Brahman-Shorthorn (fed hegari stover) | [1] 25 | 60. 2–73. 2 | 66. 6 | 58. 7–79. 9 | 69. 6 | 59. 3–74. 4 | 65. 8 |

[1] 1 carcass not graded.

TABLE 35.—*Comparison of average grades of non-Brahman and part-Brahman cattle and their carcasses*

| Feeding period and breeding of steers | Average grade as— | | |
|---|---|---|---|
| | Feeders | Slaughter cattle | Carcasses |
| At beginning of experiment: | | | |
| Non-Brahman | | 74. 1 | 65. 4 |
| Part Brahman | | 70. 2 | 65. 6 |
| Fed 120 days: | | | |
| Non-Brahman | 84. 1 | 76. 9 | 72. 9 |
| Part Brahman | 70. 7 | 70. 9 | 71. 1 |
| Fed 150 days: | | | |
| Non-Brahman | 81. 7 | 69. 0 | 70. 7 |
| Part Brahman | 69. 2 | 66. 9 | 69. 7 |
| Fed 175 days: | | | |
| Non-Brahman | 71. 7 | 69. 5 | 65. 1 |
| Part Brahman | 67. 1 | 69. 4 | 66. 0 |

From each lot of steers in the 1925–26 experiment, one representative or "standard" [3] rib sample was taken. These ribs were sent to the Department laboratories at Beltsville, Md., and Washington, D.C.

### Physical and Chemical Analyses

A physical analysis was made of a sample consisting of the ninth, tenth, and eleventh ribs from the right side of the carcass. This was separated into "eye" muscle, other lean, fat, and bone. The various samples were then analyzed chemically for water, fat, and protein, with results shown in table 36. The corresponding portion of the left-rib cut was used for color comparisons and for cooking tests.

Table 36.—*Physical analyses of ninth, tenth, and eleventh rib samples and chemical composition of their edible portion, 1925–26*

| Feeding period and breeding and number of steer | Physical analysis of entire sample | | | | | Chemical composition of edible portion | | |
|---|---|---|---|---|---|---|---|---|
| | Edible portion | | | | Bone | | | |
| | Lean | | Fat | Total | | Water | Fat | Protein |
| | Eye muscle | Other lean | | | | | | |
| At beginning of experment: | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Hereford, no. 19 | 27.9 | 38.9 | 9.4 | 76.2 | 23.8 | 65.2 | 14.6 | 19.6 |
| Shorthorn, no. 7 | 30.1 | 37.8 | 8.6 | 76.5 | 23.5 | 64.8 | 16.3 | 18.4 |
| Brahman-Shorthorn: | | | | | | | | |
| First generation, no. 4 | 35.8 | 40.6 | 4.4 | 80.8 | 19.2 | 70.6 | 7.3 | 21.3 |
| Second generation, no. 13 | 30.3 | 38.6 | 9.0 | 77.9 | 22.1 | 63.5 | 16.5 | 19.3 |
| Fed 120 days: | | | | | | | | |
| Hereford, no. 12 | 26.0 | 29.4 | 29.5 | 84.9 | 15.1 | 52.0 | 32.8 | 16.0 |
| Shorthorn, no. 82 | 30.1 | 25.7 | 29.3 | 85.2 | 14.8 | 50.9 | 34.1 | 15.7 |
| Brahman-Shorthorn: | | | | | | | | |
| First generation, no. 52 | 29.2 | 33.3 | 21.9 | 84.4 | 15.6 | 54.4 | 28.9 | 16.4 |
| Second generation, no. 44 | 25.0 | 31.5 | 29.0 | 85.5 | 14.5 | 50.4 | 34.2 | 15.7 |
| Fed 150 days:[1] | | | | | | | | |
| Hereford, no. 4 | 28.4 | 22.6 | 32.7 | 83.7 | 16.3 | ------ | ------ | ------ |
| Shorthorn, no. 80 | 30.4 | 22.4 | 31.3 | 84.1 | 15.9 | ------ | ------ | ------ |
| Brahman-Shorthorn: | | | | | | | | |
| First generation, no. 69 | 31.0 | 23.0 | 31.6 | 85.6 | 14.4 | ------ | ------ | ------ |
| Second generation, no. 41 | 28.8 | 25.6 | 31.4 | 85.8 | 14.2 | ------ | ------ | ------ |
| Average: | | | | | | | | |
| Non-Brahman | 28.8 | 29.5 | 23.3 | 81.8 | 18.2 | 58.2 | 24.4 | 17.4 |
| Part Brahman | 30.0 | 32.1 | 21.2 | 83.3 | 16.7 | 59.7 | 21.7 | 18.2 |

[1] Chemical analysis of samples in third shipment incomplete.

### Color Comparisons

In commercial channels, it is held that dark-red lean is less desirable than that possessing a brighter color. Consequently, the color of the lean portion of the eye muscle over the eleventh rib was compared with the standard color series adopted by the cooperators in these meat studies.[4] Since the series was not available at the time of the first shipment, the data obtained were for the second and third slaughterings. Comparisons were made 30 minutes after the muscle had been cut and exposed to the air. These results are reported in table 37.

[3] For description, see mimeographed outline of the cooperative meat project, A study of the factors which influence the quality and palatability of meat, issued for the cooperators by the Bureau of Animal Industry, U.S. Department of Agriculture.

[4] See footnote 3.

TABLE 37.—*Color of raw eye muscle of eleventh rib of certain steers compared with standard series of red, 1925–26* [1]

| Breeding and steer no., and feeding period | Color | Breeding and steer no., and feeding period | Color |
|---|---|---|---|
| Hereford: | | Brahman-Shorthorn: | |
| No. 12, fed 120 days | A6 | First generation: | |
| No. 4, fed 150 days | A5 | No. 52, fed 120 days | A8 |
| Shorthorn: | | No. 69, fed 150 days | A5 |
| No. 82, fed 120 days | A5 | Second generation: | |
| No. 80, fed 150 days | A5 | No. 44, fed 120 days | A6 |
| | | No. 41, fed 150 days | A5 |
| Average | A5. 25 | Average | A6. 0 |

[1] A1 represents the lightest shade of red in this series, A10 the darkest.

## COOKED-MEAT STUDIES

Standard rib samples from each lot, beginning with the first shipment of 1925–26 experimental animals, were cooked in a labora-

FIGURE 10.—An experimental rib roast. The thermometer registers the internal temperature and shows when the roast is done.

tory of the Bureau of Home Economics to determine (1) the loss in cooking and (2) the palatability.

Owing to a lack of laboratory ovens of uniform type when the four roasts from the first shipment of feeder samples were cooked, the cooking losses are not considered sufficiently comparable for publication.

The second and third shipments of steers in the 1925–26 experiment each provided four rib roasts. Laboratory ovens with glass doors and heat regulators had meanwhile been installed and were used in these and all subsequent tests. The roasts were seared for 35 minutes at oven temperatures averaging from 240° to 250° C., then cooked uncovered at 125° until the meat thermometer (fig. 10) registered 57°. Final meat temperatures ranged from 61° to 63.5°, the rise being due to the continued penetration of heat from outside

portions to the bulb of the thermometer in the center of the roast after removal from the oven.

Beef cooked in this way is rare, verging on medium-done. The slow oven temperature of 125° C. is used for palatability tests because it insures uniform cooking throughout a large proportion of a roast and thus provides comparably cooked slices for the judges.

### LOSSES THROUGH DRIPPINGS AND EVAPORATION

The losses in cooking consist of the drippings loss, which is the weight of the mixture of fat and juice that cooks out of the meat and collects in the roasting pan, and the evaporation loss, which is the difference between total loss and drippings loss. Losses were calculated for each roast as percentages of the weight of the raw meat.

The cooking losses, or shrinkage, are less than they would be if the meat were roasted at the higher oven temperature ordinarily used in household cooking. The experimental data on cooking losses are shown in table 38.

TABLE 38.—*Cooking losses of the ninth, tenth, and eleventh rib samples, expressed as percentages of the weights of the uncooked roasts, 1925–26*

| Feeding period, and breeding and steer no. | Weight of uncooked roast | Evaporation loss | Drippings loss | Total loss |
|---|---|---|---|---|
| Fed 120 days: | *Grams* | *Percent* | *Percent* | *Percent* |
| Hereford no. 12 | 3,535 | 9.1 | 4.6 | 13.7 |
| Shorthorn no. 82 | 3,143 | 11.2 | 5.2 | 16.4 |
| Brahman-Shorthorn: | | | | |
| First generation no. 52 | 4,012 | 8.0 | 3.5 | 11.5 |
| Second generation no. 44 | 3,319 | 10.0 | 5.3 | 15.3 |
| Fed 150 days: | | | | |
| Hereford no. 4 | 3,073 | 8.9 | 4.7 | 13.6 |
| Shorthorn no. 80 | 2,986 | 7.7 | 5.6 | 13.2 |
| Brahman-Shorthorn: | | | | |
| First generation no. 69 | 3,331 | 8.4 | 4.9 | 13.3 |
| Second generation no. 41 | 3,103 | 8.2 | 4.0 | 12.2 |
| Average: | | | | |
| Non-Brahman | 3,184 | 9.2 | 5.0 | 14.2 |
| Part Brahman | 3,441 | 8.7 | 4.4 | 13.1 |

### PALATABILITY STUDIES

Palatability studies were made on all the beef roasts by a cooked-meat grading committee consisting of several men and women of the Department's scientific staff. The members of the committee tasted slices from the eye muscle of the rib and portions of the inside fat of each hot roast, cooked and served without seasoning, and they compared the meat samples as to aroma, texture, flavor, tenderness, and juiciness. Cooked-meat grading charts were in process of development, but no numerical values had been assigned to the various descriptive terms, as was done in the tests of the following year. The data presented in table 39 represent the consensus of four judges' opinions on the merits of the cooked meat from representative steers of the lots designated.

TABLE 39.—*Palatability of ninth, tenth, and eleventh rib samples as determined by the cooked-meat grading committee, 1925–26*

| Breeding and steer no., and feeding period | Aroma | Texture | Flavor of lean | Tenderness | Quantity of juice |
|---|---|---|---|---|---|
| Hereford: | | | | | |
| No. 12, fed 120 days | Good | Fine | Good | Tender | Fair. |
| No. 4, fed 150 days | do | do | do | Moderately tender | Small. |
| Shorthorn: | | | | | |
| No. 82, fed 120 days | Moderately undesirable. | Coarse | Fair | Moderately tough | Do. |
| No. 80, fed 150 days | Fair | Moderately fine | Good | Moderately tender | Large. |
| Brahman-Shorthorn: | | | | | |
| First generation: | | | | | |
| No. 52, fed 120 days | Undesirable | Moderately coarse | do | do | Do. |
| No. 44, fed 150 days | Good | Very fine | do | Tender | Do. |
| Second generation: | | | | | |
| No. 69, fed 120 days | Fair | Very coarse | do | do | Moderately large. |
| No. 41, fed 150 days | Good | Moderately coarse | do | Moderately tender | Small. |

In tenderness the samples as judged by individuals varied from very tender to slightly tough. Quantity of juice ranged from large to small with various intermediate terms.

### LABORATORY STUDIES OF MEAT, 1926–27

Standard rib samples from 3 carcasses in each of the 4 lots were sent to the Department laboratories at the close of the feeding period.

TABLE 40.—*Physical analyses of ninth, tenth, and eleventh rib samples from certain steers, and chemical composition of their edible portion, 1926–27*

| Breeding and steer no.[1] | Physical analysis of entire sample | | | | | Chemical composition of edible portion | | |
|---|---|---|---|---|---|---|---|---|
| | Edible portion | | | | Bone | | | |
| | Lean | | Fat | Total | | Water | Fat | Protein |
| | Eye muscle | Other lean | | | | | | |
| Hereford: | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 98 | 25.3 | 26.2 | 26.7 | 78.2 | 21.8 | 54.5 | 26.7 | 18.3 |
| 100 | 20.8 | 35.3 | 21.9 | 78.0 | 22.0 | 55.3 | 28.5 | 16.5 |
| Shorthorn: | | | | | | | | |
| 17 | 25.7 | 24.4 | 26.7 | 76.8 | 23.2 | 52.4 | 30.7 | 16.9 |
| 21 | 24.4 | 31.6 | 15.5 | 71.5 | 28.5 | 58.2 | 23.2 | 18.2 |
| 24 | 26.3 | 23.1 | 30.4 | 79.7 | 20.2 | 48.6 | 35.9 | 15.1 |
| 76 | 26.6 | 30.3 | 13.2 | 70.0 | 29.9 | 59.0 | 20.8 | 18.3 |
| Average | 24.9 | 28.5 | 22.3 | 75.7 | 24.3 | 54.6 | 27.6 | 17.2 |
| Brahman-Shorthorn, first generation: | | | | | | | | |
| 32 | 26.8 | 31.3 | 17.2 | 75.4 | 24.6 | 60.3 | 19.5 | 18.4 |
| 34 | 23.6 | 26.8 | 28.4 | 79.8 | 21.2 | 51.6 | 32.4 | 16.0 |
| 37 | 28.4 | 30.4 | 23.0 | 81.8 | 18.2 | 55.6 | 26.5 | 17.1 |
| 59 | 22.2 | 34.7 | 15.1 | 72.1 | 27.9 | 60.6 | 20.5 | 18.3 |
| 66 | 18.7 | 27.8 | 36.0 | 82.5 | 17.5 | 46.0 | 38.0 | 14.3 |
| 69 | 22.8 | 26.6 | 28.4 | 77.7 | 22.3 | 48.9 | 34.9 | 15.5 |
| Average | 23.8 | 29.6 | 24.7 | 78.1 | 21.9 | 53.8 | 28.6 | 16.6 |

[1] All steers fed 175 days.

### Physical and Chemical Analyses

The methods of sampling and making the physical and chemical analyses conformed closely to those used the year before. Table 40 shows (1) the results of the physical analysis of the samples consisting of the ninth, tenth, and eleventh ribs from the right side of the carcasses, and (2) the chemical composition of the edible portion of the three-rib cuts.

### Color Comparisons

The color variations of the eye muscle of the eleventh rib of the same steers are recorded in table 41. The method of making comparisons was the same as that used in the preceding year.

Table 41.—*Color of raw eye muscle of eleventh rib of certain steers, 1926–27, compared with standard series of red*

| Breeding and steer no.[1] | Color [2] | Breeding and steer no.[1] | Color [2] |
|---|---|---|---|
| Hereford: | | Brahman-Shorthorn; first generation: | |
| 98 | A5 | 32 | A4 |
| 100 | A4 | 34 | A6 |
| Shorthorn: | | 37 | A1 |
| 17 | A4 | 59 | A9 |
| 21 | A5 | 66 | A5 |
| 24 | A6 | 69 | A2 |
| 76 | A4 | | |
| Average | A4.7 | Average | A4.5 |

[1] All steers fed 175 days.
[2] A1 represents the lightest shade of red in the series, A10 the darkest.

### Cooked-Meat Studies

Three rib roasts from each of the four lots were cooked for palatability tests according to the standard directions of the cooperative meat project.[5] According to this method, which embodies minor changes from that of the preceding year, beef ribs are roasted in open pans. Each roast is first seared for 20 minutes in a hot oven, 260°–270° C., then cooked slowly at a greatly reduced oven temperature, 125°, until the thermometer placed in the meat registers 58°. The roast is then removed from the oven and allowed to stand until, through penetration of the heat from the outside portions, the temperature at the center of the roast, as measured by the thermometer, is 62–63°, which is the average maximum temperature reached under these conditions.

#### Losses through drippings and evaporation

Cooking losses of 1926–27 samples are shown in table 42.

[5] See footnote 3.

TABLE 42.—*Cooking losses of the ninth, tenth, and eleventh rib samples from certain steers, expressed in percentages of the weights of the uncooked roasts, 1926–27*

| Breeding and steer no.[1] | Weight of uncooked roast | Evaporation loss | Drippings loss | Total loss |
|---|---|---|---|---|
| Hereford: | *Grams* | *Percent* | *Percent* | *Percent* |
| 98 | 3,157 | 9.3 | 3.4 | 12.7 |
| 100 | 3,464 | 9.7 | 4.3 | 14.0 |
| Shorthorn: | | | | |
| 17 | 3,702 | 9.5 | 4.5 | 14.0 |
| 21 | 3,341 | 10.8 | 3.3 | 14.1 |
| 24 | 4,720 | 8.8 | 4.5 | 13.3 |
| 76 | 2,885 | 10.5 | 2.5 | 12.9 |
| Average | 3,545 | 9.7 | 3.8 | 13.5 |
| Brahman-Shorthorn; first generation: | | | | |
| 32 | 3,000 | 10.4 | 1.5 | 11.9 |
| 34 | 4,105 | 8.9 | 4.7 | 13.6 |
| 37 | 4,694 | 10.6 | 4.2 | 14.8 |
| 59 | 3,676 | 7.9 | 3.0 | 10.9 |
| 66 | 3,487 | 7.3 | 6.5 | 13.8 |
| 69 | 4,583 | 8.6 | 5.4 | 13.9 |
| Average | 3,924 | 9.0 | 4.3 | 13.2 |

[1] All steers fed 175 days.

## PALATABILITY STUDIES

The roasts in the 1926–27 experiment were carved and sampled while hot, as in 1925–26. In recording their opinions, the judges used the official cooked-meat chart of the cooperative meat project. Aroma, flavor of fat, and flavor of lean were graded both for intensity and for desirability. Owing to the element of individual taste it is natural that desirability grades or expressions of preference should vary more, according to judges, than intensity grades. Other factors of palatability judged were the texture and tenderness of the meat and the quality and quantity of the juice. The figures presented in table 43 are the averages of the grades assigned by the 4 or 5 judges who ate the meat. In order to convey to the reader the significance of the figures, they are interpreted by the corresponding descriptive terms from the grading chart.

TABLE 43.—*Palatability* [1] *of ninth, tenth, and eleventh rib samples from certain steers as determined by the cooked-meat grading committee, 1926–27*

| Breeding and steer no.[2] | Aroma | | Texture | Flavor of fat | |
|---|---|---|---|---|---|
| | Intensity | Desirability | | Intensity | Desirability |
| Hereford: | | | | | |
| 98 | 4.8 Moderately pronounced | 5.3 Moderately desirable | 5.8 Fine | 4.8 Moderately pronounced | 5.5. Desirable. |
| 100 | 5.3 Moderately pronounced | 5.5 Desirable | 4.0 Slightly coarse | 4.3 Slightly pronounced | 5.0. Moderately desirable. |
| Shorthorn: | | | | | |
| 17 | 4.8 Moderately pronounced | 5.0 Moderately desirable | 4.8 Moderately fine | 4.6 Moderately pronounced | 4.8. Moderately desirable. |
| 21 | 5.0 Moderately pronounced | 5.8 Desirable | 5.3 Moderately fine | 5.0 Moderately pronounced | 5.8. Desirable. |
| 24 | 5.3 Moderately pronounced | 5.8 Desirable | 5.0 Moderately fine | 4.8 Moderately pronounced | 5.5. Desirable. |
| 76 | 4.6 Moderately pronounced | 5.0 Moderately desirable | 5.0 Moderately fine | 4.5 Moderately pronounced | 5.0. Moderately desirable. |
| Average | 4.9 | 5.4 | 5.0 | 4.6 | 5.3. |
| Braham-Shorthorn; first generation: | | | | | |
| 32 | 5.3 Moderately pronounced | 5.5 Desirable | 4.8 Moderately fine | 4.8 Moderately pronounced | 5.0. Moderately desirable. |
| 34 | 5.8 Pronounced | 5.8 Desirable | 4.8 Moderately fine | 5.0 Moderately pronounced | 5.8. Desirable. |
| 37 | 5.6 Pronounced | 5.6 Desirable | 4.4 Slightly coarse | 4.6 Moderately pronounced | 5.2. Moderately desirable. |
| 59 | 5.3 Moderately pronounced | 6.0 Desirable | 4.3 Slightly coarse | 4.8 Moderately pronounced | 5.8. Desirable. |
| 66 | 5.8 Pronounced | 5.3 Moderately desirable | 4.8 Moderately fine | 4.8 Moderately pronounced | 5.3. Moderately desirable. |
| 69 | 4.8 Moderately pronounced | 5.6 Desirable | 4.6 Moderately fine | 4.6 Moderately pronounced | 5.8. Desirable. |
| Average | 5.4 | 5.6 | 4.6 | 4.7 | 5.5. |

[1] The revised grading chart used by the committee provided a score of 7 as the maximum and a score of 1 as the minimum for each factor.
[2] All steers fed 175 days.

TABLE 43.—*Palatability* [1] *of ninth, tenth, and eleventh rib samples from certain steers as determined by the cooked-meat grading committee, 1926–27*—Continued

| Breeding and steer no.[2] | Flavor of lean | | Tenderness | Juice | |
|---|---|---|---|---|---|
| | Intensity | Desirability | | Quality | Quantity |
| Hereford: | | | | | |
| 98 | 5.3 Moderately pronounced | 5.0 Moderately desirable | 5.3 Moderately tender | 4.5 Moderately rich | 4.8. Moderately large. |
| 100 | 5.0 Moderately pronounced | 5.5 Desirable | 5.5 Tender | 5.0 Moderately rich | 4.8. Moderately large. |
| Shorthorn: | | | | | |
| 17 | 5.2 Moderately pronounced | 5.4 Moderately desirable | 5.5 Tender | 4.4 Slightly rich | 4.2. Slightly large. |
| 21 | 4.8 Moderately pronounced | 5.0 Moderately desirable | 4.5 Moderately tender | 4.5 Moderately rich | 4.0. Slightly large. |
| 24 | 5.0 Moderately pronounced | 5.5 Desirable | 4.3 Slightly tough | 4.8 Moderately rich | 4.5. Moderately large. |
| 76 | 4.6 Moderately pronounced | 5.2 Moderately desirable | 5.6 Tender | 3.8 Slightly rich | 4.0. Slightly large. |
| Average | 5.0 | 5.3 | 5.1 | 4.5 | 4.4. |
| Brahman-Shorthorn; first generation: | | | | | |
| 32 | 4.0 Slightly pronounced | 4.8 Moderately desirable | 4.5 Moderately tender | 3.5 Slightly rich | 3.8. Slightly large. |
| 34 | 5.0 Moderately pronounced | 5.3 Moderately desirable | 4.8 Moderately tender | 4.5 Moderately rich | 4.5. Moderately large. |
| 37 | 4.8 Moderately pronounced | 5.6 Desirable | 4.4 Slightly tough | 3.8 Slightly rich | 3.8. Slightly large. |
| 59 | 4.3 Slightly pronounced | 4.8 Moderately desirable | 3.3 Tough | 3.5 Slightly rich | 3.8. Slightly large. |
| 66 | 5.0 Moderately pronounced | 5.0 Moderately desirable | 3.8 Slightly tough | 4.3 Slightly rich | 4.5. Moderately large. |
| 69 | 5.0 Moderately pronounced | 5.4 Moderately desirable | 4.8 Moderately tender | 4.4 Slightly rich | 4.8. Moderately large. |
| Average | 4.7 | 5.1 | 4.2 | 4.0 | 4.2. |

[1] The revised grading chart used by the committee provided a score of 7 as the maximum and a score of 1 as the minimum for each factor.
[2] All steers fed 175 days.

### Resistance to Shearing

Samples of both the cooked and the uncooked meat from this experiment were tested in a new device designed to record the resistance of the meat to shearing. The results are reported in table 44.

Table 44.—*Resistance to shearing of raw and cooked meat from certain steers*

| Breeding and steer no.[1] | Resistance of eye muscle to shearing of— | | Breeding and steer no.[1] | Resistance of eye muscle to shearing of— | |
|---|---|---|---|---|---|
| | Raw, right twelfth rib | Cooked, left eleventh rib | | Raw, right twelfth rib | Cooked, left eleventh rib |
| Hereford: | *Pounds* | *Pounds* | Brahman-Shorthorn; first generation: | *Pounds* | *Pounds* |
| 98 | 72 | 24 | 32 | 89 | 36 |
| 100 | 62 | 26 | 34 | 65 | 31 |
| Shorthorn: | | | 37 | 78 | 38 |
| 17 | 96 | 32 | 59 | 84 | 51 |
| 21 | 78 | 41 | 66 | 80 | 39 |
| 24 | 99 | 34 | 69 | 89 | 29 |
| 76 | 84 | 33 | | | |
| Average | 81.8 | 31.7 | Average | 80.8 | 37.3 |

[1] All steers fed 175 days.

This instrument, as described by Black, Warner, and Wilson (*1*), consists essentially of a steel blade drilled with a hole slightly larger than the sample of meat to be tested. The sample is placed in the hole and the blade is led through a narrow slot. A spring-type self-recording dynamometer registers the force required to pull the blade through the meat.

## DISCUSSION OF DATA

A study of table 33, which compares the proportion of lean meat, bone, and fat of 16 experimental steers, shows the carcasses of the Brahman crossbreds to contain, on the average, slightly more lean and less fat and bone than the Herefords and Shorthorns. The relative weights of the wholesale cuts of the 16 steers varied but slightly, the most noteworthy difference, about 1 percent, being in the heavier loin of the non-Brahman steers.

The results of grading the cattle and carcasses also showed only small differences. Both as feeders and as slaughter cattle the Herefords and Shorthorns graded somewhat higher, on the average, but the differences in grades of carcasses were very much less and favored the Brahman crossbreds about as often as they did the non-Brahmans. In all groups of steers slaughtered directly from pasture, the average carcass grades were distinctly lower than the live-steer grades. In the case of fed cattle the differences between carcass grade and live-steer grades were less. In some instances the carcass grades were slightly higher.

Determinations of percentage of edible meat in carcasses or rib cuts were made in the case of 40 experimental steers, including both feeders and fat cattle, during the three experiments. The Brahman

crossbreds consistently yielded a slightly higher percentage of edible meat than the non-Brahmans.

In color of the meat, comparisons of the samples tested were variable and inconclusive. An average of numerical color readings slightly favored the Herefords and Shorthorns the first year these observations were made, but the next year they favored the Brahman crossbreds to a somewhat greater degree.

Comparisons of losses in cooking rib roasts likewise were variable. On the average, the losses were slightly higher for the meat of the Herefords and Shorthorns. The probable explanation lies in the somewhat greater moisture content of the average roast of these breeds of cattle, as it was observed that the roasts with the most moisture lost the most in weight through evaporation. Great variations were frequently observed, however, among individual roasts from cattle of the same breeding.

Data on the palatability of the cooked meat show only slight differences. According to the results obtained by the improved cooked-meat chart used in 1926–27, these differences favored the Hereford and Shorthorn roasts in flavor of lean and quality and quantity of juice. In flavor of fat the judges slightly preferred roasts of the Brahman crossbreds. These comments are based on average numerical ratings, but owing to the very slight differences, the limited number of samples, and natural variations in human judgment, the results do not warrant conclusions as to breed superiority on these points.

In texture of the cooked meat, however, roasts from the Brahman crossbreds were judged to be slightly but rather consistently coarser than those of the Herefords and Shorthorns.

In the mechanical test for tenderness (table 44) the raw meat from the Brahman-Shorthorns proved to be only slightly more tender than that of the Herefords and Shorthorns as a group. However, it was considerably more tender than the meat of the Shorthorns, with which it is more closely comparable. The resistance to shearing for the various groups was as follows: Brahman-Shorthorns, 80.8 pounds; Shorthorns, 89.3; Herefords, 67 pounds. The lower the resistance the more tender was the meat.

When cooked, the meat of the Brahman-Shorthorns was the least tender of the three lots, the resistance being 37.3 pounds as compared with 25 pounds for the Hereford and 35 pounds for the Shorthorn meat. However, the data show wide variations among individual animals in the different groups. Concerning this element of variation R. J. Kleberg, Jr., manager of the ranch, states in a personal communication:

> A careful study of the records of individuals of the crossbred cattle in this experiment shows that different individuals rate very differently in every respect, even as to tenderness, flavor, etc., in the meat studies. This shows clearly the possibilities for improvement which selection and breeding methods now offer to the energetic worker in this field.

For purposes of general comparison table 45 presents the essential results of the meat studies.

TABLE 45.—*Comparison*[1] *of raw and cooked rib roasts of non-Brahman and part-Brahman steers*[2]

| Breeding | Intensity of color of eye muscle of rib | Small loss in cooking | Ease of shearing | | Tenderness | Fineness of texture | Flavor of fat | | Flavor of lean | | Juice | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Raw muscle | Cooked muscle | | | Intensity | Desirability | Intensity | Desirability | Quality | Quantity |
| Hereford and Shorthorn | ------ | ------ | ------ | ++ | ++ | ++ | ------ | ------ | ++ | + | ++ | + |
| Brahman-Shorthorn | + | ++ | + | ------ | ------ | ------ | + | + | ------ | ------ | ------ | ------ |

[1] +=very slight degree of superiority; ++=slight degree of superiority.
[2] Data on intensity of color and losses in cooking are for 1925–27; other data are for 1926–27.

## SUMMARY AND CONCLUSIONS

During periods ranging from 1 to 3 years, crossbred Brahman-Hereford and Brahman-Shorthorn steers were compared with typical Hereford and Shorthorn steers, with respect to feed-lot performance, market desirability, size and weight of various parts of the body, and characteristics of the meat. Most of the experiments involving the Brahman-Shorthorns and the non-Brahmans were of 3 years' duration; those with Brahman-Herefords were for 1 year since Brahman-Hereford steers were not available after the first year. Most of the studies relating to the qualities of raw and cooked meat were of 2 years' duration and involved rib cuts from Brahman-Shorthorn, Shorthorn, and Hereford steers.

No significant differences were found in the total quantities of feed consumed in proportion to weight of the steers, but the Brahman crossbreds ate considerably more grain and cottonseed cake and a little more roughage per 100 pounds of gain.

The Brahman crossbred steers took a longer time to eat their feed than did the Shorthorns and Herefords.

Steers containing Brahman blood were heavier at weaning time than non-Brahman steers, and at that stage of development returned considerably more money per head. The price per hundredweight on the hoof was slightly higher, on the average, for the Brahman crossbreds.

At the end of 120 days' dry-lot feeding (based on an average of 2 years) the part-Brahmans sold at slightly higher prices per hundredweight and returned more money per head, even though their feed costs were slightly higher, whereas after feeding periods ranging from 150 to 179 days in length, there was a tendency for this condition to be reversed.

On account of gaining more and eating practically the same quantity of feed, the non-Brahmans made more economical feed-lot gains than the Brahman crossbreds.

No significant difference between Brahman crossbreds and non-Brahmans with respect to shrinkage while in shipment from feed lots to market was found.

The dressing percentages of Brahman crossbred lots ranged from about 2 to 4 percent higher (arithmetical difference) than those of Herefords and Shorthorns.

On account of smaller gains, greater feed consumption, and only slightly greater margins, the Brahmans are not so desirable feeders from the financial standpoint as the non-Brahmans, if purchased at the same price. However, the differences in feed-lot performance are small.

The dressed meat from the non-Brahman lots was appraised slightly higher than that from the Brahman crossbred lots, but this was about offset by the higher dressing percentage of the latter.

As noteworthy physiological and anatomical differences, the Brahman crossbreds had, on the average, smaller heads, larger hides, and smaller digestive tracts. The larger hides are explained by their loose and pendulous character, especially about the neck. The smaller digestive tract offers an explanation for the inclination of Brahman cattle to eat more frequently, and less at a time than Herefords and Shorthorns. Differences less significant from an economic standpoint were observed also in other parts and organs of the body.

Differences in the grading scores of the carcasses were too small to be significant.

The rib cuts from the Brahman crossbred steers had a slightly higher proportion of edible meat and a correspondingly smaller proportion of bone than the rib cuts from the other lots. There was no consistent difference in the chemical composition of the edible portion nor in the color of the meat.

In grading cooked meat the committee found only slight differences in the palatability of meat from the Brahman crossbreds and the non-Brahman steers. The texture of the meat from the former was rather consistently coarser than that from the Herefords and Shorthorns. The meat from the Brahman crossbreds was judged to be slightly less tender than that of the Herefords and Shorthorns. Minor differences in cooking losses through drippings and evaporation appeared to be independent of the breeding of the cattle.

Taking into consideration the various factors in cooking and palatability and varying tastes of the judges, the cooked meat of part-Brahman and non-Brahman steers is considered to be approximately equal in desirability.

Though necessarily the data presented are based on averages for the experimental cattle, individual records of the animals and their meat varied materially. Such variations, in the light of well-established principles of animal breeding, strongly indicate the possibility of improving types of beef cattle both in feed-lot efficiency and quality of meat.

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# EXPERIMENTS IN GROWING ROOTS AS FEED CROPS

By H. L. WESTOVER, *senior agronomist,* and H. A. SCHOTH, *associate agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry*

The Bureau of Plant Industry in Cooperation with the Agricultural Experiment Stations of Kansas, Oregon, Montana, and North Dakota

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## INTRODUCTION [1]

Since 1920 the Division of Forage Crops and Diseases, in cooperation with the Division of Dry Land Agriculture and several State experiment stations located in the northern part of the United States, has been conducting tests with sugar beets, mangels, rutabagas, turnips, and carrots grown as feed crops. These tests have had as objectives:

(1) A determination of the possibilities of obtaining profitable yields; (2) comparison of productiveness of the different varieties under various soil and climatic conditions; and (3) consideration of the value of root crops as compared with corn silage as a source of succulence for feeding cattle.

In most cases it is believed that the tests have been of sufficient duration to give a true indication of the possibilities of these root crops. Since general cultural and feeding recommendations have been fully covered in Farmers' Bulletin 1699,[2] these phases will not be discussed here, but the practices in conducting the tests at the various experiment stations will be briefly described.

[1] The writers acknowledge data furnished and cooperation given at various times by D. A. Savage, Hays, Kans., Morgan W. Evans, North Ridgeville, Ohio, A. E. Engbretson, Astoria, Oreg., Robert Withycombe, Union, Oreg., George W. Morgan and M. A. Bell, Havre, Mont., I. J. Jensen, N. F. Woodward, and Harold E. Tower, Moccasin, Mont., John T. Sarvis, Mandan, N.Dak., Leroy Moomaw, Dickinson, N.Dak., Samuel Garver, Redfield, S.Dak., and Ray S. Towle, Sheridan, Wyo.

[2] WESTOVER, H. L., SCHOTH, H. A., and SEMPLE, A. T. GROWING ROOT CROPS FOR LIVESTOCK. U.S. Dept. Agr. Farmers' Bull. 1699, 13 pp., illus., 1933.

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## CLIMATIC RELATIONS

As previous experience has shown that mangels, rutabagas, turnips, and carrots require relatively cool weather for satisfactory growth, the tests reported in this bulletin have been conducted in the northern half of the United States. Productivity is also closely correlated with available moisture, and for this reason precipitation records of the stations where the tests were located are presented in table 1. Since there is no Weather Bureau station at North Ridgeville, Ohio, data are given for Oberlin, about 10 miles distant.

TABLE 1.—*Annual and average precipitation (in inches) at stations named for period covered by root-crop experiments*

[Data obtained at stations whose locations are here marked with an asterisk (*) are from the records of the U.S. Weather Bureau; if the locations are marked with a dagger (†) the data are from the records of the Division of Genetics and Biophysics of the Bureau of Plant Industry]

| Stations | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Redfield, S.Dak.* | 22.03 | ------ | 20.93 | 16.49 | 22.61 | 16.17 | 13.00 | 26.76 | 15.34 | 17.12 | 22.17 | 14.78 | 18.85 |
| Havre, Mont.† | 11.20 | 13.37 | 10.26 | 16.03 | 12.52 | 17.64 | 8.90 | 19.04 | 11.74 | 12.25 | 8.88 | 8.29 | 12.51 |
| Moccasin, Mont.† | 18.36 | 15.48 | 15.38 | 18.58 | 12.14 | 13.50 | 14.79 | 16.02 | 12.21 | 13.28 | 12.18 | 10.71 | 14.39 |
| Dickinson, N.Dak.† | 15.81 | 15.76 | 18.20 | 19.67 | 15.13 | 12.19 | 13.11 | 19.62 | 15.30 | 17.21 | 13.79 | 16.17 | 16.00 |
| Mandan, N.Dak.† | 12.69 | 15.23 | 17.35 | 14.41 | 16.25 | 14.06 | 11.51 | 20.30 | 16.85 | 14.22 | 17.38 | 17.44 | 15.64 |
| Hays, Kans.* | 21.28 | 18.46 | 18.98 | 27.10 | 14.51 | 23.02 | 16.45 | 27.21 | 29.94 | 26.57 | 25.03 | 26.06 | 22.88 |
| Sheridan, Wyo.† | 13.64 | 10.61 | 17.95 | 25.18 | 13.98 | 17.95 | 14.90 | 22.16 | 17.77 | 17.05 | 8.68 | 14.63 | 16.21 |
| Oberlin, Ohio* | 29.81 | 37.19 | 31.18 | 35.57 | 42.49 | 35.69 | 45.02 | 37.15 | 36.32 | 43.52 | 27.61 | 30.41 | 36.00 |
| Corvallis, Oreg.* | 37.12 | 41.05 | 38.45 | 37.07 | 37.87 | 34.07 | 40.04 | 47.87 | 39.87 | 24.45 | 23.68 | 39.13 | 36.72 |
| Astoria, Oreg.* | 80.90 | 93.69 | ------ | 55.40 | 67.90 | 62.91 | ------ | 90.97 | 69.49 | 52.62 | 58.28 | 88.47 | 72.06 |
| Union, Oreg.* | 14.76 | 14.79 | 8.26 | 17.40 | 9.42 | 11.61 | 15.88 | 16.48 | 9.45 | 10.99 | 13.51 | 9.88 | 12.70 |

In general, the root crops tested yielded best at those stations receiving the highest annual precipitation. Where the rains have occurred at opportune times, however, some remarkably satisfactory yields have been obtained at stations having a relatively low rainfall.

## EXPERIMENTS AT HAYS, KANS.

The tests with root crops at the Fort Hays Branch Station, State Agricultural Experiment Station, Hays, Kans., have been under way only 4 years. The data are given in table 2. The 1929, 1930, and 1932 seedings were on fallow and the 1931 seedings on land that had been in root crops the previous year. Seedings have been made early in May in 42-inch rows with a grain drill with a press-wheel attachment. About 10 days or 2 weeks after emergence the plants were thinned. Mangels have been spaced 15 to 24 inches, rutabagas 12 to 18 inches, turnips 15 to 20 inches, and carrots 13 to 20 inches. As shown in table 1, the annual average precipitation at Hays, Kans., for the years 1920–31, inclusive, was 22.88 inches.

TABLE 2.—*Annual and average acre yields of root crops at the Fort Hays Branch Station, State Agricultural Experiment Station, Hays, Kans., 1929–32*

| Crop and variety | Tops, green weight | | | | | Roots | | | | | Yields of roots in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1929 | 1930 | 1931[1] | 1932 | Average | 1929 | 1930 | 1931[1] | 1932 | Average | *Comparable years* | *Percent* |
| Mangels: | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | | |
| Mammoth Long Red | 2.82 | 2.96 | 1.65 | 6.34 | 3.44 | 12.81 | 11.49 | 8.34 | 25.67 | 14.58 | 4 | 100.0 |
| Danish Sludstrup | 3.03 | 2.99 | 1.08 | 5.27 | 3.09 | 13.24 | 12.11 | 7.89 | 19.53 | 13.19 | 4 | 90.5 |
| Giant Red Eckendorf | 1.92 | 1.86 | .93 | 2.72 | 1.86 | 11.23 | 11.43 | 9.27 | 15.06 | 11.75 | 4 | 80.6 |
| Golden Tankard | 1.62 | 2.09 | 1.23 | 4.60 | 2.39 | 6.53 | 7.77 | 6.48 | 16.36 | 9.29 | 4 | 63.7 |
| Rutabagas: | | | | | | | | | | | | |
| American Purple Top | 3.89 | 4.16 | 1.44 | [2] | 3.16 | 6.79 | 4.19 | 1.95 | [2] | 4.31 | 3 | 39.6 |
| Hurst Monarch | 2.09 | 3.50 | 1.29 | [2] | 2.29 | 4.27 | 4.07 | 1.62 | [2] | 3.32 | 3 | 30.5 |
| Carter Hardy Swede | 2.09 | 2.28 | 1.23 | [2] | 1.87 | 4.27 | 3.71 | 2.76 | [2] | 3.58 | 3 | 32.9 |
| Turnips: | | | | | | | | | | | | |
| Purple Top Strap-leaved | 2.01 | [2] | [2] | ------ | 2.01 | 4.04 | [2] | 1.17 | ------ | 2.61 | 2 | 24.7 |
| Purple Top White Globe | 1.52 | [2] | [2] | ------ | 1.52 | 3.44 | [2] | 1.23 | ------ | 2.34 | 2 | 22.1 |
| Carrots: | | | | | | | | | | | | |
| Ox-heart | 1.28 | [4] | 1.08 | ------ | 1.18 | 3.35 | [4] | 2.16 | ------ | 2.76 | 2 | 26.1 |
| Long Orange | 1.22 | [4] | .87 | ------ | 1.05 | 2.96 | [4] | 1.98 | ------ | 2.47 | 2 | 23.4 |

[1] All root crops were badly damaged by army worms.
[2] Yields not reported. Badly damaged by heat and root rot. Not included in averages.
[3] Badly damaged by lice, drought, and root rot. Not included in averages.
[4] Destroyed by rabbits. Not included in averages.

The average yields indicate that with the exception of mangels root crops have little promise in western Kansas. The high summer temperatures are unfavorable for turnips, especially when sown in the spring. Jack rabbits are very likely to destroy carrots unless the crop is fenced, though a large acreage might minimize this trouble. Rutabagas stand summer heat better than turnips but in the average season are not very productive. Mangels are the only roots that have produced a greater tonnage of succulence than sorghum silage. Mammoth Long Red mangels gave a 4-year average yield of 14.58 tons as compared with 9.45 tons per acre of Early Sumac sorgo, but much more labor was involved in growing the mangels. In most cases weights were also obtained of the tops, which constituted the following percentages of the total weights of the various roots: Mangels, about 20 percent; rutabagas, 35 to 40 percent; carrots, approximately 30 percent; and turnips 40 percent.

## EXPERIMENTS AT HAVRE, MONT.

The experiments with root crops under dry-land conditions at the Northern Montana Branch Station, State Agricultural Experiment Station, Havre, Mont., have been carried on continuously since 1920. The seedings were made on summer-fallow, the land usually being spring-tooth harrowed as early as conditions permitted, to encourage germination of the weed seeds, Russian-thistles in particular, so that many of the weeds, which later might become troublesome, could be destroyed by a thorough shallow cultivation just before seeding. In the early years of this experiment the seed was sown with a grain drill, but more recently a beet drill has been used. The seed usually was sown in 36-inch rows early in May, although in about one half of the years reseeding was necessary on account of uneven emergence resulting from soil crusting following a dashing shower, or from too

dry weather after seeding. Insect damage also contributed to the injury of stands at emergence, necessitating reseeding. After the plants attained sufficient size they were blocked out with a hoe and thinned by hand to single plants 8 to 10 inches apart. The roots were harvested, usually between October 1 and October 15, a beet lifter being used to loosen them. Mangels, especially the Golden Tankard variety, were much more easily removed from the ground than sugar beets. Yields secured from these crops during the years 1920–32, inclusive, are given in table 3.

TABLE 3.—*Annual and average acre yields of root crops at the Northern Montana Branch Station, State Agricultural Experiment Station, Havre, Mont., 1920–32*

| Crop and variety | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 |
|---|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| Sugar beets | [1] 2.84 | [1] 5.85 | 4.36 | [2] | 3.69 | 6.30 | 3.80 | 7.29 |
| Mangels: | | | | | | | | |
| Mammoth Long Red | 4.57 | 7.07 | 5.43 | [2] | 5.24 | 13.17 | 5.71 | 7.98 |
| Golden Tankard | 3.26 | 6.52 | 6.64 | [2] | 5.49 | 11.30 | 5.23 | 7.29 |
| Danish Sludstrup | 2.70 | 7.38 | 6.50 | [2] | 6.35 | 14.16 | 7.43 | 6.46 |
| Giant Red Eckendorf | | | 5.92 | [2] | 4.19 | 14.62 | 6.86 | 10.86 |
| Rutabagas: | | | | | | | | |
| American Purple Top | 1.77 | [2] | 1.86 | [2] | 6.11 | 12.03 | 5.23 | |
| Carter Hardy Swede | 1.17 | [2] | 3.33 | [2] | 5.35 | 9.21 | 3.19 | 9.01 |
| Hurst Monarch | 1.25 | [2] | 1.16 | [2] | 3.60 | 9.75 | 4.44 | |
| Turnips: | | | | | | | | |
| Purple Top Strap-leaved | | 2.81 | 3.41 | [2] | 6.82 | 9.74 | 4.15 | 8.87 |
| Purple Top White Globe | | | | [2] | | | | 11.00 |
| Carrots: | | | | | | | | |
| Mastodon | [3] | [3] | [3] | | .28 | [3] | [3] | 4.95 |
| Long Orange | [3] | [3] | [3] | | .94 | [3] | [3] | 5.04 |

| Crop and variety | 1928 | 1929 | 1930 | 1931 | 1932 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Comparable years* | *Percent* |
| Sugar beets | 10.30 | 3.42 | 5.76 | 2.21 | 5.83 | 5.14 | 12 | 67.8 |
| Mangels: | | | | | | | | |
| Mammoth Long Red | 16.94 | 4.30 | 8.10 | 1.69 | 10.78 | 7.58 | 12 | 100.0 |
| Golden Tankard | 13.30 | 3.58 | 5.34 | 1.65 | 6.72 | 6.36 | 12 | 83.9 |
| Danish Sludstrup | 19.22 | 5.76 | 7.67 | 1.97 | 9.17 | 7.90 | 12 | 104.2 |
| Giant Red Eckendorf | 13.05 | 3.30 | 7.37 | .92 | 6.64 | 7.37 | 10 | 92.9 |
| Rutabagas: | | | | | | | | |
| American Purple Top | | | | | | 5.40 | 5 | 79.1 |
| Carter Hardy Swede | 13.67 | 2.76 | 3.77 | .91 | 5.68 | 5.28 | 11 | 69.2 |
| Hurst Monarch | | | | | | 4.04 | 5 | 59.2 |
| Turnips: | | | | | | | | |
| Purple Top Strap-leaved | 13.79 | 3.48 | 2.52 | 1.20 | 5.05 | 5.62 | 11 | 71.6 |
| Purple Top White Globe | 16.73 | 4.26 | 2.68 | 2.19 | 7.26 | 7.35 | 6 | 88.6 |
| Carrots: | | | | | | | | |
| Mastodon | 12.07 | 2.35 | 2.75 | 0 | 4.08 | 3.78 | 7 | 48.1 |
| Long Orange | 7.40 | 2.45 | 2.27 | 0 | 3.50 | 3.09 | 7 | 39.3 |

[1] Average of several varieties.
[2] Destroyed by insects. Not included in averages.
[3] Destroyed by jack rabbits. Not included in averages.

These yields are satisfactory considering the low annual precipitation, which averaged only 12.72 inches during the years covered by the test. Yields, compared with many other dry-land crops, were especially good in the drier seasons of 1922, 1926, 1929, and 1930. Results in the extremely adverse year of 1931, however, were unsatisfactory, due partly to lack of moisture reserve in the fallowed land on which the roots were planted.

Mangels, with averages ranging from 6.36 to 7.90 tons per acre, produced the highest average yield of the roots tested, returning a considerably greater tonnage of succulent feed than corn or sunflowers, the green weight of which averaged only 3.13 and 3.81 tons per acre, respectively, during 11 years of the period 1920–32 when yield data were obtained.

Sugar beets, rutabagas, and turnips were considerably less productive than mangels. The lowest yields were obtained from carrots which were destroyed by jack rabbits in nearly one half of the seasons.

Weights of tops, obtained in most seasons, showed a wide variation from year to year in relation to the total weight. As a rule, mangel tops constituted 25 to 30 percent of the total weight, with extremes of a little more than 10 to about 50 percent. In the case of rutabagas and turnips, the proportion of tops to total weight averaged approximately 35 percent, with extreme variations even greater than in the case of mangels.

## EXPERIMENTS AT MOCCASIN, MONT.

The experiments with root crops at the Judith Basin Branch Station, State Agricultural Experiment Station, Moccasin, Mont., began in 1920 and continued until 1929, covering a period of 10 years. The average annual precipitation for the years 1920–31 amounted to 14.39 inches. The seed was generally sown on land that was fallowed the previous summer and which was prepared in the early spring by cultivating with a spring-tooth harrow or duck-foot cultivator and finished with a smoothing harrow. The seeding was made in 36-inch rows early in May with a hand drill. The roots were harvested after the first killing frost. Annual as well as average yields obtained in these tests are given in table 4.

TABLE 4.—*Annual and average acre yields of root crops at the Judith Basin Branch Station, State Agricultural Experiment Station, Moccasin, Mont., 1920–29, inclusive*

| Crop and variety | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | Comparable years | Percent |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | | |
| Sugar beets | ---- | ---- | 0.77 | 9.10 | 3.77 | 3.96 | 7.73 | (1) | (1) | (1) | 5.07 | 5 | 79.0 |
| Mangels: | | | | | | | | | | | | | |
| Mammoth Long Red | 3.36 | 0.74 | .98 | 11.39 | 4.61 | 5.17 | 9.94 | (2) | 7.32 | .89 | 5.17 | 9 | 100.0 |
| Golden Tankard | 3.27 | .19 | 1.03 | 8.98 | 4.24 | 4.02 | 9.13 | (1) | (1) | .52 | 4.41 | 8 | 84.7 |
| Danish Sludstrup | 2.23 | .69 | .52 | 12.05 | 3.75 | 3.96 | 9.79 | (1) | (1) | (1) | 4.71 | 7 | 91.1 |
| Giant Red Eckendorf | (2) | (2) | .91 | 12.60 | 5.45 | 4.79 | 12.09 | (2) | 6.27 | 1.10 | 6.17 | 7 | 107.2 |
| Rutabagas: | | | | | | | | | | | | | |
| American Purple Top | 2.89 | 1.51 | 1.91 | 11.83 | 5.86 | 6.49 | 6.38 | 12.31 | 9.57 | 1.68 | 5.27 | 9 | 108.4 |
| Carter Hardy Swede | 2.31 | 1.68 | 1.38 | 9.87 | 6.68 | 2.97 | 5.28 | (1) | (1) | (1) | 4.31 | 7 | 83.4 |
| Hurst Monarch | 3.00 | 1.57 | 3.55 | 13.31 | 8.64 | 3.66 | 6.30 | 4.06 | 6.27 | (1) | 5.72 | 8 | 106.6 |
| Turnips: | | | | | | | | | | | | | |
| Purple Top Strap-leaved | (1) | (1) | (1) | 9.54 | 7.18 | 4.51 | 3.58 | 12.97 | 9.68 | 1.62 | 7.01 | 6 | 91.9 |
| Carrots: | | | | | | | | | | | | | |
| Long Orange | 1.57 | .22 | (2) | 4.18 | .43 | 2.83 | 2.67 | (2) | 1.87 | (2) | 1.97 | 7 | 32.4 |
| Mastodon | 1.43 | .42 | (2) | 6.82 | .92 | 3.93 | 4.90 | (2) | 1.65 | (2) | 2.87 | 7 | 47.2 |

[1] No seed sown; not considered in averages.
[2] Destroyed by rabbits and insects; not considered in averages.

A striking fact brought out by these data is the small difference in the average yields of mangels, rutabagas, and turnips. The yields are not sufficient to offer much encouragement to the production of root crops on a large scale, since the indications are that nearly as much succulence can be obtained from silage corn at considerably less expense. Jack rabbits destroyed the carrots on several occasions, and the average yields were too low to recommend the crop to the farmer.

This is the only dry-land station where higher average yields were obtained from rutabagas than from mangels. During the period 1920–26, the only years for which comparable data are available, the green weights obtained from corn and sunflowers averaged 3.70 tons and 4.53 tons, respectively, as compared with an average yield of 7.01 tons from the Purple Top Strap-leaved turnip, the highest-yielding root crop. Much more difficulty, however, has been encountered in obtaining satisfactory stands of the roots.

## EXPERIMENTS AT DICKINSON, N.DAK.

The tests with root crops at the Dickinson substation, State Agricultural Experiment Station, Dickinson, N.Dak., have been carried on continuously since 1920 to determine their possibilities as a source of feed for cattle in this locality. The seed usually was sown on summer fallow or following a cultivated crop, such as corn or potatoes, the land being cultivated in the early spring with a disk or duck-foot harrow to induce germination of the weed seeds. Just before seeding the root crops, the weeds were destroyed with a spring-tooth or spike-tooth harrow. The seed was sown in 36- or 42-inch rows early in May with a hand drill. In a month or 6 weeks the rows were blocked out with a hoe and then thinned by hand to single plants, carrots being spaced 6 inches and mangels 8 to 12 inches. The average annual precipitation for the years 1920–31 amounted to 16 inches.

The yields as given in table 5 are not large, but certain roots could be produced to advantage if it were not for the hand labor involved. Mangels generally gave somewhat better yields than sugar beets, rutabagas, or turnips. Carrots were the least productive, but they have possibilities as a crop for human consumption locally, because with favorable soil and moisture conditions, the income from carrots is likely to be greater than from almost any other root or garden crop. Corn for silage, although producing no more succulence per acre, can be grown much more easily and cheaply. For the small farmer, however, who cannot afford a silo, root crops would appear to have possibilities even under these conditions.

TABLE 5.—*Annual and average acre yields of root crops at the Dickinson Substation, State Agricultural Experiment Station, Dickinson, N.Dak., 1920–31*

| Crop and variety | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 |
|---|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| Sugar beets | 4.16 | 1.01 | 5.00 | (1) | 1.55 | 4.61 | 3.45 | 9.24 |
| Mangels: | | | | | | | | |
| Mammoth Long Red | 6.48 | 1.64 | 9.70 | (1) | 7.65 | 3.75 | 3.86 | 9.95 |
| Golden Tankard | 5.04 | .80 | 12.80 | (1) | 3.50 | 4.68 | 2.86 | 7.34 |
| Danish Sludstrup | 5.04 | 1.31 | 10.95 | (1) | 9.15 | 4.60 | 5.54 | 13.47 |
| Giant Red Eckendorf | | | | | | | | |
| Rutabagas: | | | | | | | | |
| American Purple Top | 2.78 | 1.46 | 5.40 | 17.75 | 5.65 | 4.01 | 2.95 | 9.95 |
| Carter Hardy Swede | 2.95 | 1.87 | 5.92 | 20.35 | 6.60 | 4.05 | 2.27 | 10.08 |
| Hurst Monarch | 3.58 | 1.49 | 6.66 | 10.20 | 2.70 | 3.42 | 2.86 | 13.06 |
| Turnips: | | | | | | | | |
| Purple Top Strap-leaved | | | | | 10.00 | 3.40 | 2.92 | 16.20 |
| Purple Top White Globe | | | 8.16 | 11.00 | 1.15 | 5.42 | 2.74 | 10.89 |
| Carrots: | | | | | | | | |
| Long Orange | .76 | .33 | 2.28 | (1) | .50 | 5.36 | 1.52 | 3.45 |
| Mastodon (white) | 3.94 | .72 | 2.32 | 4.30 | .75 | 5.42 | 1.37 | 4.95 |
| Ox-heart | 4.38 | .45 | 4.50 | (1) | 1.20 | 4.39 | .78 | 3.05 |

| Crop and variety | 1928 | 1929 | 1930 | 1931 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Comparable years* | *Percent* |
| Sugar beets | 11.87 | 2.95 | | 0.45 | 4.43 | 10 | 58.4 |
| Mangels: | | | | | | | |
| Mammoth Long Red | 25.69 | 6.09 | 3.94 | .97 | 7.25 | 11 | 100.0 |
| Golden Tankard | 18.62 | 5.28 | 3.59 | .68 | 5.93 | 11 | 81.8 |
| Danish Sludstrup | 33.00 | 4.60 | 4.59 | .60 | 8.44 | 11 | 116.4 |
| Giant Red Eckendorf | 21.87 | 8.21 | 5.65 | .95 | 9.17 | 4 | 100.0 |
| Rutabagas: | | | | | | | |
| American Purple Top | 14.94 | (2) | (2) | (2) | 7.21 | 8 | 68.6 |
| Carter Hardy Swede | 16.97 | 2.24 | 3.34 | .43 | 6.42 | 11 | 71.2 |
| Hurst Monarch | 14.05 | (2) | (2) | (2) | 6.45 | 8 | 69.6 |
| Turnips: | | | | | | | |
| Purple Top Strap-leaved | 13.44 | 4.75 | 5.24 | .31 | 7.03 | 8 | 90.8 |
| Purple Top White Globe | 16.69 | 5.86 | 5.22 | .45 | 6.76 | 9 | 79.0 |
| Carrots: | | | | | | | |
| Long Orange | 6.60 | 3.56 | .70 | .49 | 2.32 | 11 | 32.0 |
| Mastodon (white) | 10.23 | 4.17 | 1.31 | .73 | 3.35 | 11 | 45.0 |
| Ox-heart | 5.70 | 3.66 | 1.08 | .73 | 2.72 | 11 | 37.5 |

[1] Stand failed; not included in averages.
[2] No seed sown; not included in averages.

## EXPERIMENTS AT MANDAN, N.DAK.

Root crops were tested in a limited way at the United States Northern Great Plains Field Station, Mandan, N.Dak., for several years, the results being given in table 6. In the majority of seasons the yields were relatively low, owing to poor stands resulting from unfavorable weather at a critical time or to a moisture deficiency later in the season. As shown in table 1, the average annual precipitation from 1920 to 1931, inclusive, was 15.64 inches. In reasonably favorable seasons, such as occurred in 1922 and 1927, the yields of mangels especially were very satisfactory, exceeding that of corn grown for silage. While mangels produced a greater average tonnage for the 4 years 1922, 1923, 1926, and 1927, corn silage is a more dependable source of succulence, since less difficulty is encountered in obtaining and maintaining a stand. In 3 of the 7 years included in the test no harvest of mangels was obtained, owing to failure to obtain stands in 1928 and 1929 and to a freeze in 1925, while fair yields of silage corn were obtained in each of these years. Furthermore, much less labor is involved in growing corn.

TABLE 6.—*Annual and average acre yields of root crops at the United States Northern Great Plains Field Station, Mandan, N.Dak.*

| Crop and variety | 1922 | 1923 | 1926 | 1927 | 1928 | 1929 | Average [1] | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Comparable years | |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | | *Percent* |
| Sugar beets | 4.65 | 1.71 | 1.19 | 9.40 | (2) | (2) | 4.24 | 4 | 51.2 |
| Mangels: | | | | | | | | | |
| Mammoth Long Red | 12.00 | 2.66 | 1.94 | 16.54 | (2) | (2) | 8.29 | 4 | 100.0 |
| Golden Tankard | ------ | ------ | 1.90 | 14.76 | (2) | (2) | 8.33 | 2 | 90.2 |
| Rutabagas: | | | | | | | | | |
| Carter Hardy Swede | 7.05 | 1.39 | 2.95 | 10.25 | 7.66 | 3.78 | 5.41 | 4 | 65.3 |
| Turnips: | | | | | | | | | |
| Purple Top Strap-leaved | 3.15 | 0 | 6.75 | 9.96 | 8.70 | 8.71 | 4.97 | 4 | 60.0 |

[1] Does not include 1924, when no root crops were sown, and 1925, when all were killed by a freeze May 16.
[2] No stand obtained; not considered in averages.

## EXPERIMENTS AT NORTH RIDGEVILLE, OHIO

The forage-crop field experiments at North Ridgeville, Ohio, have included a limited number of root crops each year since 1926, the yields being given in table 7. With the more favorable soil and climatic conditions, the annual precipitation amounting to about 36 inches a year at Oberlin about 10 miles distant, the average production has been considerably in excess of that obtained under the drier conditions in the northern Great Plains, but not equal to the yields obtained from the nearly ideal conditions found in some parts of the Pacific Northwest. As is generally the case, mangels have been much more productive than turnips and rutabagas. The average tonnage is also considerably greater than is usually obtained from silage corn in this locality. The Mastodon variety of carrots has given some remarkable yields, the average for a period of years being nearly equal to that of mangels.

TABLE 7.—*Annual and average acre yields of root crops at North Ridgeville, Ohio*

| Crop and variety | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Comparable years | |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | | *Percent* |
| Sugar beets | 11.67 | ------ | 9.85 | 9.40 | 7.49 | 16.52 | 10.99 | 5 | 52.1 |
| Mangels: | | | | | | | | | |
| Mammoth Long Red | 22.80 | 17.78 | 16.79 | 19.68 | 16.53 | 29.58 | 20.53 | 6 | 100.0 |
| Golden Tankard | 20.50 | 13.55 | 11.54 | 11.60 | 9.49 | 20.53 | 14.54 | 6 | 70.8 |
| Barre Sludstrup | (1) | 17.31 | 18.25 | 14.97 | (1) | (1) | 16.84 | 3 | 93.1 |
| Rutabagas: | | | | | | | | | |
| Carter Hardy Swede | (1) | 2.33 | 5.43 | 1.43 | 6.13 | 10.46 | 5.16 | 5 | 25.7 |
| Hurst Monarch | (1) | 3.33 | 7.79 | 1.57 | 7.45 | 10.89 | 6.21 | 5 | 30.9 |
| Turnips: | | | | | | | | | |
| Purple Top Strap-leaved | (1) | 2.90 | 6.95 | 1.02 | 6.15 | 7.69 | 4.94 | 5 | 24.6 |
| Carrots: | | | | | | | | | |
| Mastodon | 16.18 | 14.54 | 19.52 | 15.05 | 10.03 | 25.98 | 16.88 | 6 | 82.2 |
| Long Orange | (1) | 10.74 | 1.39 | 11.51 | 7.53 | 16.77 | 9.59 | 5 | 47.9 |

[1] No seeding.

## EXPERIMENTS AT ASTORIA, OREG.

Experiments with mangels, rutabagas, and turnips at the John Jacob Astor Branch Station, State Agricultural Experiment Station, Astoria, Oreg., have been in progress since 1923. The average annual precipitation at this station for the years 1920–31 amounted to 72.06 inches. The yields as given in tables 8 and 9 do not always represent a true comparison of the productivity of the different kinds of roots, owing to the fact that they were sometimes grown under quite different soil conditions and have not always received the same fertilizer treatment. Manure has been applied to all crops at the approximate rate of 20 tons per acre. In addition, mangels usually have had an application consisting of 100 pounds of ammonium sulphate, 200 pounds of superphosphate, 100 pounds of bone meal, and 150 pounds of potassium sulphate. Rutabagas and turnips were given 460 pounds of superphosphate per acre in addition to the manure until 1928, when they received 2 tons of lime and 300 pounds of superphosphate per acre with the usual application of manure. Mangels were grown on tideland, from 1924 to 1928, inclusive, while rutabagas and turnips were grown on the upland in 1923, 1924, and 1925; on both tideland and upland in 1926 and 1927; and on tideland only from 1928 to 1932, inclusive. In 1928 the stand of mangels was reduced 20 to 50 percent by cold weather after the seeds had germinated, thus affecting the yields appreciably.

TABLE 8.—*Annual and average acre yields of root crops grown on tideland at the John Jacob Astor Branch Station, State Agricultural Experiment Station, Astoria, Oreg.*

| Crop and variety | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | 1932 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | *Comparable years* | *Percent* |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | | |
| Sugar beets | 15.18 | 5.26 | 12.40 | 5.40 | 5.20 | ------ | ------ | ------ | ------ | 8.68 | 5 | 41.9 |
| Mangels: | | | | | | | | | | | | |
| Mammoth Long Red | 18.31 | 20.32 | 18.75 | 25.20 | 21.00 | ------ | ------ | ------ | ------ | 20.71 | 5 | 100.0 |
| Golden Tankard | 15.62 | 21.75 | 16.50 | 19.70 | ------ | ------ | ------ | ------ | ------ | 18.39 | 4 | 89.1 |
| Danish Sludstrup | 23.65 | 24.30 | 16.70 | 25.90 | 28.30 | ------ | ------ | ------ | ------ | 23.77 | 5 | 114.7 |
| Giant Red Eckendorf | 21.88 | 16.14 | 21.70 | 26.35 | 14.00 | ------ | ------ | ------ | ------ | 20.01 | 5 | 96.6 |
| Prizewinner | 24.15 | 27.26 | 16.00 | 26.45 | 29.80 | ------ | ------ | ------ | ------ | 24.73 | 5 | 119.4 |
| Giant Half Sugar | 23.93 | 18.91 | 24.15 | 21.00 | 17.00 | ------ | ------ | ------ | ------ | 20.99 | 5 | 101.4 |
| Red Intermediate | 19.15 | 16.42 | 19.15 | 25.80 | 15.25 | ------ | ------ | ------ | ------ | 19.35 | 5 | 93.4 |
| Barre Sludstrup | ------ | 23.13 | ------ | 21.10 | 20.60 | ------ | ------ | ------ | ------ | 21.61 | 3 | 97.5 |
| Rutabagas: | | | | | | | | | | | | |
| Skirving Improved | ------ | ------ | 37.75 | 32.52 | 31.25 | 30.90 | 36.45 | 27.80 | 42.95 | 34.23 | 3 | 156.4 |
| Magnum Bonum | ------ | ------ | 47.15 | 34.00 | 32.42 | 34.50 | 37.10 | 30.55 | 40.90 | 36.66 | 3 | 174.9 |
| Hurst Monarch | ------ | ------ | 40.00 | 31.45 | 32.37 | 34.70 | 37.50 | 33.10 | 38.10 | 35.31 | 3 | 159.9 |
| Acquisition | ------ | ------ | 41.85 | 27.50 | 40.35 | 35.35 | 35.85 | 28.65 | 36.07 | 35.08 | 3 | 168.9 |
| American Purple Top | ------ | ------ | ------ | 31.85 | 30.25 | 34.65 | 35.25 | ------ | ------ | 33.00 | 2 | 134.4 |
| Improved American Purple Top | ------ | ------ | 31.25 | ------ | 28.07 | 38.95 | 36.20 | ------ | 42.22 | 35.34 | 2 | 149.2 |
| Bangholm Giant | ------ | ------ | ------ | ------ | 33.85 | ------ | 36.00 | 27.60 | 37.90 | 33.84 | 1 | 161.2 |
| Up-to-Date | ------ | ------ | 29.25 | 27.95 | ------ | ------ | ------ | 30.10 | 46.15 | 33.36 | 2 | 130.1 |
| Green Top | ------ | ------ | 37.35 | 31.05 | 31.05 | ------ | ------ | 36.15 | ------ | 33.90 | 3 | 153.1 |
| Turnips:[1] | | | | | | | | | | | | |
| Imperial Green Globe | ------ | ------ | ------ | 23.65 | 32.55 | 30.95 | 27.10 | 49.80 | 53.70 | 36.29 | 2 | 121.6 |
| Cowhorn | ------ | ------ | ------ | 31.10 | 31.45 | 68.00 | 31.15 | 41.00 | 52.80 | 42.58 | 2 | 135.4 |
| Danish Bortfeld | ------ | ------ | ------ | 31.35 | 32.30 | 53.50 | 42.35 | 45.10 | 49.45 | 42.34 | 2 | 137.8 |
| Green Top Aberdeen | ------ | ------ | ------ | ------ | 31.90 | 41.90 | 34.10 | 42.45 | 36.50 | 37.37 | 1 | 151.9 |
| Pomeranian White Globe | ------ | ------ | ------ | 24.90 | ------ | 59.40 | 31.00 | 48.55 | 52.70 | 43.31 | 1 | 98.8 |

[1] Yields include tops.

TABLE 9.—*Annual and average acre yields of rutabagas and turnips grown on uplands at the John Jacob Astor Branch Station, State Agricultural Experiment Station, Astoria, Oreg.*

| Crop and variety | 1923 | 1924 | 1925 | 1926 | 1927 | Average | Yields in comparison with Skirving Improved rutabaga | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | *Comparable years* | *Percent* |
| Rutabagas: | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | | |
| Skirving Improved | 20.00 | 27.50 | 25.11 | 29.60 | 17.05 | 23.85 | 5 | 100.0 |
| Magnum Bonum | 20.85 | 24.00 | 31.35 | 31.95 | 20.65 | 25.76 | 5 | 108.0 |
| Hurst Monarch | ------- | 29.87 | 26.33 | 29.75 | 17.75 | 25.93 | 4 | 104.4 |
| American Purple Top | ------- | 20.60 | 29.85 | 31.80 | 16.80 | 24.76 | 4 | 99.8 |
| Improved American Purple Top | 20.65 | 16.15 | ------- | 32.05 | ------- | 22.95 | 3 | 89.3 |
| Bangholm Giant | 21.00 | ------- | ------- | 30.00 | 16.40 | 22.47 | 3 | 101.1 |
| Champion | ------- | ------- | 29.87 | 27.25 | 21.00 | 26.04 | 3 | 108.9 |
| Acquisition | ------- | ------- | 30.55 | 31.50 | 20.00 | 27.35 | 3 | 114.3 |
| Up-to-Date | ------- | ------- | 30.85 | 33.20 | 21.20 | 28.42 | 3 | 118.8 |
| Crimson King | ------- | ------- | 29.54 | 31.90 | 19.50 | 26.98 | 3 | 112.8 |
| Green Top | ------- | ------- | ------- | 33.80 | 22.45 | 28.13 | 2 | 120.6 |
| Turnips: [1] | | | | | | | | |
| Imperial Green Globe | 31.37 | 34.90 | 42.82 | 33.70 | 20.80 | 32.71 | 5 | 137.1 |
| Green Top Aberdeen | 27.50 | ------- | 41.09 | 22.60 | 19.55 | 27.69 | 4 | 120.7 |
| Hardy Green Round | 28.20 | ------- | 46.13 | 32.60 | 20.25 | 31.80 | 4 | 138.6 |
| Cowhorn | 26.94 | ------- | 46.37 | 26.60 | 17.45 | 29.34 | 4 | 127.9 |
| Pomeranian White Globe | ------- | ------- | 46.13 | 32.75 | 19.75 | 32.88 | 3 | 137.5 |

[1] Weights given include roots and tops.

Yields of mangels and rutabagas as given in the tables are of roots only, while the turnip yields include roots and tops. Turnips are usually fed without topping, since the tops are regarded as being nearly equal to the roots for feeding. Mangels were not included in the upland tests, but on tideland both turnips and rutabagas were more productive. When allowance is made for weight of tops, rutabagas as an average exceeded turnips in tonnage. No striking or consistent differences in productivity of the different varieties is apparent. Both rutabagas and turnips gave much higher yields on tideland than on upland.

In 1923 weights were obtained of mangel tops, and they were found to constitute 20 to 35 percent of the total weight, depending upon the variety, the average for all varieties being about 30 percent.

Root crops produced a considerably greater tonnage than was obtained from oat-and-pea silage, which amounted to from 7 to 9 tons per acre.

## EXPERIMENTS AT CORVALLIS, OREG.

The root-crop experiments at the State Agricultural Experiment Station, Corvallis, Oreg., have included sugar beets and several varieties of mangels. Rutabagas, turnips, and carrots were not included, as previous experience had shown rather definitely that turnips and rutabagas are of little value in the Willamette Valley because of root maggot, while carrots do not produce sufficient tonnage to compete with mangels as feed for livestock. The tests were conducted on a clay-loam soil that was manured before plowing for root crops. The seed usually was sown early in May and the plants thinned by hand when the fourth leaf appeared. The crop was usually harvested in October. The yields from this test are given in table 10.

TABLE 10.—*Annual and average acre yields of root crops at the State Agricultural Experiment Station, Corvallis, Oreg., 1922–32*

| Crop and variety | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 |
|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| Sugar beets | | | 9.20 | 11.40 | 9.07 | 11.28 | 9.78 |
| Mangels: | | | | | | | |
| Mammoth Long Red | 21.39 | 12.40 | 17.08 | 14.26 | 15.01 | 16.57 | 16.11 |
| Half Sugar | 22.95 | 13.20 | 15.23 | 17.09 | 13.22 | 22.38 | 19.14 |
| Golden Tankard | 17.23 | 9.95 | 14.25 | 12.92 | 13.97 | 18.05 | 14.22 |
| Danish Sludstrup | 21.37 | 11.45 | 13.78 | 15.76 | 15.07 | 19.41 | 15.81 |
| Red Eckendorf | 16.42 | 9.95 | 13.18 | | 15.75 | 18.94 | 14.99 |
| Red Intermediate | | | 13.40 | 13.65 | 13.77 | 19.85 | 17.28 |
| Barre Sludstrup | | | | | 10.92 | 16.96 | 18.42 |
| Heavy Cropper | 21.45 | | 12.86 | | | 19.95 | 17.70 |
| Prize Winner | | | | | 13.83 | 18.41 | 13.44 |
| Yellow Eckendorf | | | | | | 13.48 | 17.70 |
| Yellow Globe | | | 14.90 | 14.44 | 14.16 | | |
| Kirsche Ideal | | | | | 11.75 | 16.59 | 13.50 |
| Yellow Intermediate | | | | | | | 15.50 |
| Giant Intermediate | 21.64 | 11.75 | 12.46 | | | | |

| Crop and variety | 1929 | 1930 | 1931 | 1932 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Comparable years* | *Percent* |
| Sugar beets | 7.49 | 7.28 | 6.12 | 7.69 | 8.81 | 9 | 60.6 |
| Mangels: | | | | | | | |
| Mammoth Long Red | 8.46 | 16.65 | 12.33 | 14.29 | 14.96 | 11 | 100.0 |
| Half Sugar | 13.35 | 13.07 | 13.21 | 16.01 | 16.26 | 11 | 108.7 |
| Golden Tankard | 9.81 | 10.50 | 12.20 | 12.89 | 13.27 | 11 | 88.7 |
| Danish Sludstrup | 11.41 | 9.36 | 12.45 | 14.37 | 14.57 | 11 | 97.4 |
| Red Eckendorf | 10.06 | 8.88 | 12.06 | 14.58 | 13.48 | 10 | 89.7 |
| Red Intermediate | 9.45 | 11.02 | 13.05 | 13.33 | 13.87 | 9 | 95.5 |
| Barre Sludstrup | 11.62 | 11.70 | 13.05 | 15.33 | 14.00 | 7 | 98.6 |
| Heavy Cropper | 10.39 | 9.10 | 10.98 | | 14.63 | 7 | 94.3 |
| Prize Winner | 10.03 | | 13.06 | 15.42 | 14.03 | 6 | 101.7 |
| Yellow Eckendorf | 10.68 | 9.44 | 12.12 | 13.51 | 12.82 | 6 | 91.1 |
| Yellow Globe | 16.31 | 11.84 | 13.10 | | 14.13 | 6 | 101.2 |
| Kirsche Ideal | | 7.65 | | | 12.37 | 4 | 76.9 |
| Yellow Intermediate | 8.36 | 14.90 | 11.46 | | 12.56 | 4 | 93.8 |
| New Perfect Gem Intermediate | 12.57 | 12.32 | 11.07 | | 11.99 | 3 | 96.1 |
| Lord Worden | 13.51 | 12.96 | 13.17 | | 13.21 | 3 | 105.9 |
| Giant Intermediate | | | | | 15.28 | 3 | 90.1 |

Although there was some variation in production from year to year, the annual yields as well as the average of nearly all varieties of mangels were consistently good and considerably in excess of sugar beets.

No silage-crop data are available for the period covered by this test. During the years 1927–32 drilled corn, spaced 8 inches apart in the row, averaged 6.58 tons per acre, which was about half the yield obtained from mangels during the same period. Sunflowers, spaced 12 inches apart in the row, averaged 13.98 tons per acre, which was nearly equal to the yield obtained from mangels.

## EXPERIMENTS AT UNION, OREG.

Experiments with mangels were conducted at the Eastern Oregon Branch Station, State Agricultural Experiment Station, Union, Oreg., from 1924 to 1930 and with carrots from 1924 to 1931. In preparing the land for these crops it was plowed to a depth of 7 inches in the spring and worked down to a fine seed bed. Every other year 8 tons per acre of stable manure were applied. The seed was sown between April 23 and May 25 in rows usually 18 inches apart.

Considering the precipitation, which averaged only 12.70 inches for 1920–31, the yields of carrots and mangels were remarkably satisfactory, as shown in table 11. This is due to the fact that the soil on which these tests were conducted is a very fertile sandy loam, usually being subirrigated throughout the growing season. While mangels generally were most productive, two varieties of carrots gave yields that approximated those of most varieties of mangels in comparable years.

TABLE 11.—*Annual and average acre yields of root crops at the Eastern Oregon Branch Station, State Agricultural Experiment Station, Union, Oreg., 1924–31* [1]

| Crop and variety | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 | 1931 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | *Comparable years* | *Percent* |
| Mangels: | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | | |
| Mammoth Long Red | 26.12 | 35.59 | 2.7 | 25.6 | 12.8 | 35.0 | 13.0 | ------ | 21.54 | 7 | 100.0 |
| Danish Sludstrup | 24.54 | 41.73 | 5.0 | 28.5 | 16.3 | 38.7 | 14.0 | ------ | 24.11 | 7 | 111.9 |
| Giant Red Eckendorf | 29.37 | 40.32 | 4.9 | 32.9 | 15.99 | 38.7 | 13.8 | ------ | 25.14 | 7 | 116.7 |
| Golden Tankard | 21.63 | 31.13 | 3.0 | 16.2 | 13.5 | 32.6 | 14.4 | ------ | 18.92 | 7 | 87.8 |
| Giant Intermediate | 24.79 | 38.69 | 5.6 | 23.4 | 13.7 | 36.4 | 11.0 | ------ | 21.94 | 7 | 101.9 |
| Half Sugar | 26.27 | 40.21 | 4.7 | 19.0 | 18.4 | ------ | ------ | ------ | 21.72 | 5 | 105.6 |
| Danish Barre | ------ | 45.79 | 3.1 | ------ | ------ | ------ | ------ | ------ | 24.44 | 2 | 127.7 |
| Kirsche Ideal | ------ | ------ | 6.6 | 24.6 | 16.0 | 34.3 | ------ | ------ | 20.38 | 4 | 107.1 |
| Danish Giant Half Sugar | ------ | 42.32 | 3.6 | ------ | ------ | 37.5 | 10.1 | ------ | 23.38 | 4 | 108.4 |
| Carrots: | | | | | | | | | | | |
| White Belgian | 31.7 | 30.98 | 23.0 | 19.9 | 7.7 | 13.1 | 16.1 | 6.4 | 20.35 | 7 | 94.4 |
| Danvers Half Long | ------ | ------ | ------ | 19.8 | 9.6 | 13.8 | 20.6 | ------ | 15.76 | 4 | 73.8 |
| Short White | 19.13 | 26.78 | 25.5 | ------ | ------ | ------ | ------ | ------ | 23.80 | 3 | 110.6 |
| Yellow Belgian | ------ | ------ | ------ | 21.6 | ------ | 10.0 | 20.2 | 4.3 | 14.03 | 3 | 70.4 |
| Improved Short White | ------ | ------ | ------ | 18.9 | ------ | ------ | ------ | ------ | 18.90 | 1 | 73.8 |
| Yellow Giant | 27.53 | 22.88 | 14.2 | ------ | ------ | ------ | 21.5 | 2.9 | 17.80 | 4 | 111.3 |
| Chantenay | 23.6 | 21.83 | 15.0 | 18.7 | 5.7 | 10.9 | 16.2 | 5.1 | 15.99 | 7 | 74.2 |

[1] During the season of 1926 the mangel crop was severely damaged by curly top. No planting of mangels was made in 1931.

## EXPERIMENTS AT REDFIELD, S.DAK.

The forage-crop field experiments at Redfield, S.Dak., included tests with root crops each year since 1920. Seedings were made the latter part of April or early in May with a garden drill on fall-plowed land that was variously cropped the previous season and then prepared by disking and harrowing before seeding. Considerable difficulty was encountered in obtaining satisfactory stands of sugar beets and mangels, due to the tendency of the soil to crust. Freezes and insects also took their toll, necessitating reseeding on several occasions. When the stands were uniform the plants were spaced about as follows: Carrots, 4 to 6 inches; rutabagas and turnips, 8 to 10 inches; and mangels and sugar beets, 10 to 12 inches. On the average, roots were cultivated four times during the season. They were harvested by hand early in October just before the ground was likely to freeze. The yields obtained are given in table 12.

TABLE 12.—*Annual and average acre yields of root crops at Redfield, S.Dak., 1920–32*

| Crop and variety | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 [1] | 1927 |
|---|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| Sugar beets | 13.70 | 8.50 | 5.10 | 5.24 | 7.87 | 5.79 | 0 | 13.05 |
| Mangels: | | | | | | | | |
| Mammoth Long Red | 30.58 | 17.48 | 13.68 | 16.46 | 19.55 | 20.45 | 0 | 32.02 |
| Golden Tankard | 14.22 | 9.93 | 9.68 | 6.57 | 12.65 | 10.90 | 0 | 20.47 |
| Danish Sludstrup | 20.79 | 14.26 | 10.05 | 10.23 | 22.36 | 18.96 | 0 | 25.85 |
| Giant Red Eckendorf | ------ | ------ | 8.97 | 10.68 | 21.42 | 11.18 | 0 | 25.33 |
| Kirsche Ideal | ------ | ------ | ------ | ------ | ------ | 15.50 | 0 | 25.45 |
| Rutabagas: | | | | | | | | |
| American Purple Top | 11.83 | 4.57 | 4.36 | 4.22 | 7.77 | 1.88 | 0 | 11.68 |
| Carter Hardy Swede | 9.68 | 2.64 | 3.64 | 4.63 | 9.21 | 2.70 | 0 | 12.24 |
| Hurst Monarch | 9.27 | 2.52 | 1.97 | 3.49 | 5.21 | 1.95 | 0 | 12.48 |
| Turnips: | | | | | | | | |
| Purple Top Strap-leaved | ------ | 3.86 | 3.35 | [2] 1.25 | 8.26 | 3.52 | 0 | 10.83 |
| Purple Top White Globe | ------ | ------ | ------ | 4.48 | 9.86 | 3.85 | 0 | 14.64 |
| Carrots: | | | | | | | | |
| Long Orange | 6.33 | 5.34 | 1.06 | 1.88 | 2.75 | 3.00 | 0 | 8.25 |
| Mastodon | 9.82 | 5.06 | 2.75 | 3.56 | 2.76 | 3.41 | 0 | 10.16 |
| Ox-heart | 11.06 | 9.03 | 1.77 | 3.41 | 4.77 | 2.94 | 0 | 8.85 |
| White Belgian Field | ------ | ------ | ------ | ------ | ------ | ------ | ------ | 7.20 |

| Crop and variety | 1928 | 1929 | 1930 | 1931 | 1932 | Average | Yields in comparison with Mammoth Long Red mangel | |
|---|---|---|---|---|---|---|---|---|
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Comparable years* | *Percent* |
| Sugar beets | 4.62 | 2.42 | 5.64 | 2.59 | 5.41 | 6.15 | 13 | 41.0 |
| Mangels: | | | | | | | | |
| Mammoth Long Red | 12.60 | 6.94 | 14.93 | 4.09 | 6.14 | 14.99 | 13 | 100.0 |
| Golden Tankard | 6.13 | 3.45 | 9.90 | 1.93 | 3.73 | 8.43 | 13 | 56.2 |
| Danish Sludstrup | 9.44 | 5.42 | 13.05 | 3.63 | 9.33 | 12.57 | 13 | 83.9 |
| Giant Red Eckendorf | 9.09 | 4.14 | 10.02 | 2.28 | 5.16 | 9.84 | 11 | 73.7 |
| Kirsche Ideal | 8.85 | 5.06 | 11.65 | 4.68 | 8.94 | 10.02 | 8 | 82.5 |
| Barre Sludstrup | 8.33 | 4.99 | 8.07 | 2.04 | 7.71 | 6.23 | 5 | 69.7 |
| Pedigreed Ideal | ------ | 4.36 | 12.44 | 3.47 | 6.62 | 6.72 | 4 | 83.7 |
| Rutabagas: | | | | | | | | |
| American Purple Top | 4.36 | 1.06 | 2.15 | 0 | 2.35 | 4.33 | 13 | 28.9 |
| Carter Hardy Swede | 5.30 | .91 | 2.59 | 0 | 3.48 | 4.38 | 13 | 29.2 |
| Hurst Monarch | 4.28 | 1.21 | 1.87 | 0 | 1.96 | 3.55 | 13 | 23.7 |
| Turnips: | | | | | | | | |
| Purple Top Strap-leaved | 5.71 | 1.53 | 2.53 | 0 | .98 | 3.40 | 12 | 24.8 |
| Purple Top White Globe | 5.14 | 1.54 | 2.41 | 0 | 1.40 | 4.33 | 10 | 32.5 |
| Carrots: | | | | | | | | |
| Long Orange | 4.46 | 3.58 | 4.65 | .45 | 2.41 | 3.40 | 13 | 22.7 |
| Mastodon | 2.94 | 3.40 | 4.98 | .38 | 2.49 | 3.98 | 13 | 26.6 |
| Ox-heart | 5.61 | 3.69 | 5.35 | 1.25 | 3.00 | 4.67 | 13 | 31.2 |
| White Belgian Field | 2.74 | 2.48 | 5.82 | .50 | 2.94 | 3.61 | 6 | 28.2 |

[1] Root crops in 1926 were a complete failure due to drought and unusually warm weather.
[2] Low yield in 1923 due to bacterial soft rot.

With an average annual precipitation of 18.85 inches for 1920–31, Mammoth Long Red mangels, the most productive root crop, gave an average yield of 14.99 tons per acre. This is nearly double the average yield of 8.08 tons green weight per acre of corn and 7.70 per acre of sunflowers. In a reasonably favorable season the production from all roots has been satisfactory, though mangels far exceeded rutabagas, turnips, and carrots. During the dry seasons that have been unusually frequent in recent years, the yields have been low. However, in spite of the higher yields obtained from mangels, as compared with corn for silage, it is likely that on the large farm the production of the latter will continue mainly because of the amount of hand labor involved in growing root crops.

## EXPERIMENTS AT SHERIDAN, WYO.

A limited test of roots has been sown at the United States Dry Land Field Station, Sheridan, Wyo., on three occasions. The 1927 seedings were made on land that had been in sorghum the previous season, the 1928 seedings followed Sudan grass, while the 1929 seedings were made on summer fallow. The heavy rain on May 31, 1929, caused such a poor stand that no weights were taken that year. The acre yields from the other seedings are given in table 13. While the tests here recorded are very limited, the yields from the 1927 seeding are highly satisfactory and are indicative of what may be expected in a reasonably favorable season.

TABLE 13.—*Acre yields of root crops at the United States Dry Land Field Station, Sheridan, Wyo.*

| Crop and variety | 1927 | 1928 | Crop and variety | 1927 | 1928 |
|---|---|---|---|---|---|
| Mangels: | *Tons* | *Tons* | | *Tons* | *Tons* |
| Mammoth Long Red | 11.96 | 3.80 | Rutabagas, Carter Hardy Swede | 12.24 | 11.77 |
| Golden Tankard | 17.15 | 1.43 | Turnips, Purple Top Strap-leaved | 13.88 | 9.96 |

## SUMMARY

For several years variety trials with mangels, rutabagas, turnips, and carrots have been in progress in several of the Northern States both under dry-land conditions and with abundant rainfall. In all these tests, with the exception of those conducted at Astoria, Oreg., Sheridan, Wyo., and Moccasin, Mont., mangels yielded somewhat more than other roots tested, the Mammoth Long Red variety usually being at or near the top. At Moccasin, Mont., rutabagas and mangels produced approximately the same tonnage. At Astoria, Oreg., both rutabagas and turnips had considerable advantage over mangels. Carrots generally were the least productive of the roots tested. Varietal differences in yields of rutabagas, turnips, and carrots were not very consistent.

While roots in general produced a greater amount of succulence per acre than was obtained under similar conditions from corn or some other crop grown for silage, the large amount of hand labor they require tends to restrict their production very materially. In certain limited areas where conditions are especially favorable, as in the Pacific Northwest, and in some of the more humid Eastern States, where the seasons are too short and too cool for corn, root crops are grown to advantage as feed for dairy cattle and sheep. For the farmer with a small dairy herd or one who cannot afford a silo, root crops can advantageously supply succulence for winter feed whether under dry-land or humid conditions. Furthermore, a few roots for special purposes, such as for feeding poultry and as conditioners, are very desirable.

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# SHORTENING THE REST PERIOD OF THE POTATO

By WILLIAM STUART, *senior horticulturist*, and E. H. MILSTEAD, *chief scientific aid, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

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## INTRODUCTION

Bernard's (*2*) [1] discovery in 1878 that plants, like animals, were rendered insensible when subjected to ether fumes, while serving to establish a close physiological relationship between members of the animal and vegetable kingdom, did not indicate the after-effect upon plants that were in a state of rest at the time of the anaesthetization. It was not until 12 years later (1890) that Johannsen (*6*), of the Royal Danish School of Copenhagen, Denmark, conceived the idea that ether or chloroform might be successfully used to shorten the rest period of plants. The presentation in 1893 of a paper by Johannsen (*7*) before the Royal Academy of Science of Copenhagen, giving the results of experimental studies on the effect of anaesthetizing willows and bulbous plants, at once aroused keen interest in the subject. This stimulation of interest in the possibilities involved in the use of anaesthetics in plant forcing became general, and it was not long before some European nursery firms were advertising anaesthetized dormant hard-wooded flowering plants for sale.

Later studies have shown that many chemicals other than those producing anaesthesia can be employed with satisfactory results in shortening the rest period of many classes of plants. It has also been found that the subjection of certain plants in a state of rest to relatively low or high temperature or to immersion in warm water shortens the rest period.

[1] Italic numbers in parentheses refer to Literature Cited, p. 30.

33086°—34——1

## REST OR DORMANT PERIOD

In much of the literature dealing with methods for hastening the germination of potato tubers the terms "rest period" and "dormancy period" are used synonymously. Because in a certain sense these two terms are not identical in meaning it seems desirable to attempt the formulation of a clearer definition of their meaning. The rest period as applied to outdoor plants, in northern latitudes especially, is that interval between the cessation of active growth and the time when it is again resumed, assuming, of course, that temperature is not the inhibiting factor. Dormancy, on the other hand, is an all-inclusive term, embracing not only the normal rest period of the plant but also that interval of time beyond the true rest period, in which growth is inactive as a result of low temperature.

Most deciduous and herbaceous outdoor plants in northern latitudes have certain well-defined periods of rest, the intensity of which is not uniformly alike. Johannsen (*6*) suggestively divided this resting stage into three periods which he called "before rest", "middle rest", and "after rest." In the first and third rest periods the plant is more easily incited into growth than in the middle or deep-rest period, during which it responds less readily to external stimuli, such as heat, moisture, and light. In the case of the potato the deep-rest period begins about the time of tuber maturity and continues from 70 to 90 days. Appleman (*1*) in his study of the rest period of potato tubers found that under natural planting conditions the McCormick potato would begin to germinate about 90 days after harvesting.

After potato tubers emerge from the middle or deep-rest period further inactivity is entirely dependent on the temperature at which they are held. This dormancy or inactivity is entirely apart from the rest period and should not be confused with it. Hence, the true effectiveness of any agency employed to hasten germination can only be properly evaluated when the treatment is made during the first portion of the deep-rest period.

## PREVIOUS EXPERIMENTAL STUDIES

The earliest experimental effort to abridge the normal rest period of the potato in the United States that has come to the writers' attention was reported by McCallum (*9*) in 1909. This report was based on studies conducted during the crop seasons of 1907 and 1908. According to that author these studies were the outcome of an inquiry relating to tuberization in potatoes, which indicated the necessity of a more adequate knowledge of the many factors involved in tuber formation. One of these factors was the shortening of time for the crop to mature, in addition to the time saved by green sprouting the seed before planting. It was thought that germination might be hastened by treating the cut seed or whole tubers with some stimulative agent. Among the most effective of those employed by McCallum (*9*) were ethyl bromide, carbon tetrachloride, ammonia, gasoline, ethylene chloride, bromine, etc. The best success followed treatment with ethyl bromide. Manganese chloride and ethyl ether were found to induce a marked acceleration in tuber formation.

Appleman (*1*) found that the rest period could be shortened and sprouting induced by the removal of the skin, especially around the eyes.

On the assumption that oxygen might be a limiting factor, tubers were wrapped in cotton previously saturated with hydrogen peroxide and then stored in moist chambers, which in turn were buried in moist sawdust under a greenhouse bench.

Tubers wrapped in cotton saturated with a 3-percent solution of hydrogen peroxide showed 100-percent germination in 28 days, as compared with 43 days in the case of those wrapped in cotton soaked in a 1-percent solution.

The effect of anaesthetics was also tried by Appleman (*1*) on blocks of tissue 1 centimeter square, each containing a single eye. Ether gas proved ineffective, but marked results were obtained from ethyl bromide. The periods of treatment tested were 2, 4, 5, 10, and 20 minutes, while whole tubers were treated for 15 and 30 minutes. The quickest response was obtained from the 5-minute treatment.

In some experiments conducted by Rosa (*11*) in 1923 it was found that the rest period of cut seed potatoes could be materially abridged by soaking the seed in solutions of $NaNO_3$, $Ca(NO_3)_2$, $Mg(NO_3)_2$, $Mn(NO_3)_2$, $KMnO_4$, $(NH_4)_2SO_4$. The conclusions drawn were that the sprouting of dormant tubers can be hastened and the percentage of germination within a limited period after treatment can be increased by dipping the cut seed pieces in a 0.5 molecular solution of sodium nitrate ($NaNO_3$). Other oxidizing substances to which the cell is permeable and which are not toxic when used in proper concentration had a similar effect.

In a later report Rosa (*12*) presented the results of studies conducted the winter of 1923–24 and the fall of 1924. These studies involved a determination of the relation of temperature to the nitrate of soda treatment of cut seed. Lots of tubers were soaked for 1 hour in a 0.5 molecular nitrate of soda solution at 18°, 24°, 31°, and 40° C. (64°, 74.8°, 87.5°, and 104° F., resp.). It was found that the average time required for germination decreased slightly as the temperature increased to 36° C.[2] (96.8° F.), while severe injury occurred at 40° C. (104° F.). In later field tests it was observed that treatments in a given strength and period were considerably more toxic to the seed piece during hot weather than during cool weather.

Ethylene gas was first tested by Rosa (*13*) in 1923 as an agent for shortening the rest period of potatoes. Three varieties, American Giant (White Rose), Charles Downing (Idaho Rural), and Irish Cobbler were used in the experiment. Cut seed pieces were exposed for 4 weeks to three concentrations of the gas, except in the case of the Irish Cobbler sets which were only exposed to the two higher strengths. The gas concentrations employed were 1: 1,000, 1: 5,000, and 1: 100,000 parts. The chambers were ventilated every day or two during the treatment, and the gas concentration restored after each ventilation period.

It was found that the American Giant responded most readily to the treatment, with the Charles Downing and Irish Cobbler following in the order mentioned. Evidently these varieties have a longer or deeper rest period than the American Giant.

Considerable impetus was given to the study of the most effective means of shortening the rest period of potatoes through the publication of a paper by Denny (*3*), which included a study of the effect of 224 different chemical substances. In these tests ethylene chlorhy-

[2] No mention is made by Rosa of having soaked cut seed in a 36° C. solution.

drin ($ClCH_2CH_2OH$) and the thiocyanates of sodium and potassium stood out most prominently in hastening germination.

The germination of cut seed of Triumph was found to be materially hastened when soaked in solutions of ethylene chlorhydrin varying in concentration from 3 to 10 cc per liter. Freshly harvested Irish Cobblers responded to a 4-cc-per-liter concentration in which the cut sets were soaked for 2 hours.

The volatility of ethylene chlorhydrin also permitted its use as a gas. Three methods of application were used. The first was by placing 0.5 to 1 cc of ethylene chlorhydrin in a shallow pan resting on the cut sets, which were held in an airtight container of 1-liter capacity for a period of from 16 to 24 hours.

The second method consisted in arranging the cut sets in layers about 6 inches deep in tight containers and then covering each layer with burlap saturated with a solution of ethylene chlorhydrin and holding them overnight. The concentration used to saturate the burlap cloth was 100 cc per liter.

The third method consisted in dipping the cut seed in a 3-percent ethylene chlorhydrin solution and holding them in a closed container for 16 to 24 hours.

Fairly satisfactory results were obtained from the first and last methods.

The rest period of cut sets was materially shortened when the tubers were soaked in 3- or 2-percent solutions of either sodium or potassium thiocyanate. Soaking in a 1-percent solution was found to be less effective, and distinct injury resulted from the use of a 4-percent solution.

Treatment of cut sets by soaking 1 hour in a 1-percent solution of thiourea caused the development of multiple sprouts. In a later experiment additional evidence was obtained by Denny (*4*) in regard to the peculiar reaction of potato buds to this treatment. Multiple sprouts from one-eyed seed pieces were observed in the Irish Cobbler, Triumph, Rural New Yorker No. 2, and McCormick varieties.

In studying the relationship of temperature to the effectiveness of chemical treatment of seed potatoes to hasten germination, Denny (*5*) found that when cut seed was held for 16 to 24 hours in a closed jar after dipping in an ethylene-chlorhydrin solution a temperature of 95° F. caused a considerable rotting of the seed, while at 59° the treatment was more or less ineffective. Favorable responses in breaking the rest period were obtained between 68° and 90°. It was also found that when the treatment consisted in soaking the cut seed in a 1- to 2-percent solution of either sodium or potassium thiocyanate the temperature of the solution was of less importance. This observation confirms that of Rosa (*12*), to which reference was made earlier in this publication.

Any review of previous experimental evidence, however brief, would be incomplete without discussing the effect of temperature alone in shortening the rest period.

Among the workers who have used other than chemical means for breaking the rest period, Müller-Thurgau (*10*) may be regarded as one of the earliest. He was able to force potatoes into growth by storing them for a month after harvesting at a temperature of 32° F. In a later paper negative results were reported from a 1-hour bath in water at 35° C. (95° F.).

Loomis (*8*) found that the rest period of potatoes can be broken in 4 weeks by storage during July in the attic of a low-roofed building. Extended studies prove the efficacy of storage temperatures around 86° F. in shortening the rest period of potato tubers.

Tubers weighing 3 and 4 ounces, selected from a given lot of freshly dug potatoes, germinated more readily and made a stronger growth than 1- and 2-ounce tubers from the same lot. The difference was lost as the tubers passed through the rest period.

## DEPARTMENT OF AGRICULTURE STUDIES

The studies upon which the present report is based were primarily undertaken with a view to securing additional information in regard to varietal responses to chemical treatments for breaking the rest period. A preliminary study of such varietal responses was begun in the fall and winter of 1928–29 and was continued more extensively and thoroughly during 1929–30 and 1930–31.

The chemical treatments and methods of application were essentially those recommended by F. E. Denny, who collaborated with the Department in the fall of 1927, conducting chemical treatments of newly harvested Maine-grown Triumph seed potatoes for immediate planting at Belle Glade, Fla. The potatoes were harvested and shipped direct to Florida by express, where they were promptly treated and planted. In this experiment Dr. Denny discovered that seed dipped in a solution of ethylene chlorhydrin and kept in a closed container for 24 hours, when the day temperature was 90° F. or above, was distinctly injured.

## EXPERIMENTAL TREATMENTS

### SEASON OF 1928–29

Preliminary studies during 1928–29 included observations on the behavior or reaction of a number of varieties to the ethylene-chlorhydrin treatment and a more detailed study with the Irish Cobbler and Dakota Red (Jersey Red Skin) varieties of the effect of different strengths and periods of treatment in which sodium thiocyanate (Na SCN) as well as ethylene chlorhydrin was used. The treated seed in all of the earlier experiments was immediately planted in 4-inch pots and germinated in a greenhouse temperature of from 55° to 75° F.

In no instance were the tubers treated as soon after harvesting as is considered desirable to obtain the most striking differences between the date of germination of the treated and untreated seed. This delay was partly unavoidable because the stock used in the experiment was grown in Maine, harvested about September 25, and held until a convenient time to prepare the material for shipment to Washington. The shipment was sent about October 10, which meant arrival at Washington sometime between October 20 and 25. Other duties delayed the treatment until November 12, or approximately 48 days from the time of harvesting.

Notwithstanding these delays, some interesting data were obtained, as shown in table 1. Because of the small sample of each variety it was not possible to use check lots; hence the chief interest of this study is the relative response of the several varieties to the ethylene-chlorhydrin treatment.

TABLE 1.—*Effect of treating cut seed of different varieties of potatoes by dipping in a 4-percent solution of ethylene chlorhydrin and storing in a closed container for 24 hours to hasten germination*

[Sets treated Nov. 12, planted Nov. 13, 1928]

| Variety | Sets | Rate of germination in— | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 9 days | 11 days | 13 days | 18 days | 21 days | 24 days | 28 days |
| | *Number* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Noroton Beauty | 30 | | | | 46.7 | 80.0 | 100 | |
| Charles Downing | 30 | | | | 76.7 | 83.3 | 93.3 | 93.3 |
| Scotch Rose | 30 | | | 10.0 | 53.3 | | 63.3 | 70.0 |
| Early Manistee | 30 | | | 50.0 | 86.7 | 93.3 | 93.3 | 100 |
| White Star | 30 | | | | 10.0 | 16.7 | 23.3 | 30.0 |
| White Ohio | 30 | | | | | | | 3.3 |
| Extra Early Rockford | 30 | | | | | | | 0 |
| White Rose (White Elephant, etc.) | 30 | | | | 30.0 | 36.7 | 66.7 | 76.7 |
| Early Rose | 30 | | | 16.7 | 86.7 | 93.3 | 93.3 | 100 |
| Beauty of Hebron | 30 | | | 6.7 | 53.3 | 70.0 | 86.7 | 90.0 |
| Burbank (Low-top) | 30 | | | 6.7 | 33.3 | 46.7 | 50.0 | 50.0 |
| Pride of Multnomah | 30 | | | | 13.3 | 13.3 | 20.0 | 20.0 |
| Gold Coin | 30 | | | | 13.3 | 20.0 | 23.3 | 33.3 |
| Russet Rural (Late Petoskey) | 30 | | | | 3.3 | 3.3 | 3.3 | 6.7 |
| Peachblow (Red McClure) | 30 | | | | 10.0 | 10.0 | 10.0 | 10.0 |
| Earliest of All | 30 | | | | 63.3 | 70.0 | 80.0 | 86.7 |
| Dakota Seedling | 30 | | | | 10.0 | 13.3 | 13.3 | 16.7 |
| Adirondack | 30 | | | | 26.7 | 30.0 | 36.7 | 50.0 |
| Queen-of-the-Valley | 30 | | | | | 3.3 | 6.7 | 6.7 |
| Dakota Red | 30 | | | | | | | 0 |
| Early St. George | 29 | | | 17.2 | 75.9 | 93.1 | 96.5 | 100 |
| Prolific (Brown Beauty) | 29 | 6.7 | 16.7 | 43.3 | 93.3 | 96.7 | 100.0 | |
| Keeper | 29 | | 6.7 | 10.0 | 50.0 | 70.0 | 80.0 | 90.0 |
| Charles Downing | 20 | | | 10.0 | 30.0 | 70.0 | 80.0 | 95.0 |
| Seedling No. 9 | 30 | | | | 33.3 | 63.3 | 76.7 | 83.3 |
| McCulloch | 30 | | 30.0 | 60.0 | 86.7 | 96.7 | | 96.7 |
| Cow Horn (light type) | 20 | | 5.0 | 30.0 | 43.3 | 50.0 | 60.0 | 80.0 |
| Prince Albert | 30 | | 13.3 | 30.0 | 76.7 | 90.0 | 93.3 | 96.7 |

Of the 27 varieties, or 28 lots, treated, Prolific (Brown Beauty) showed the quickest response, with nearly 7-percent germination in 9 days. In 11 days after treatment 5 varieties gave germination counts varying from 5 to 30 percent, while after 13 days nearly half of the 28 lots showed varying degrees of response. The most interesting feature of these data is the behavior of the Dakota Red, the White Ohio, and the Extra Early Rockford, the latter being a strain of the Early Ohio. Neither the Extra Early Rockford nor the Dakota Red showed evidence of germination after 28 days, and only 1 of the 30 White Ohio seed pieces sprouted.

The value of any treatment for shortening the rest period of the potato is its effectiveness in securing a satisfactory percentage of germination in a minimum time interval. A study of the data in table 1 shows that 6 of the 27 varieties—Early Manistee, Early Rose, Early St. George, McCulloch, Prolific, and Prince Albert—gave a germination of 90 percent or over in 21 days, while the Charles Downing and Noroton Beauty required 24 days and Beauty of Hebron and Keeper 28 days. In other words, only onethird of the varieties responded with a 90-percent, or better, germination in 28 days.

In order to obtain additional light on the efficacy of different strengths and periods of treatment with ethylene chlorhydrin and sodium thiocyanate, 27 lots of 20 seed pieces each of the Irish Cobbler were treated on November 27, 1928. These treatments varied from 6 to 48 hours.

The data in table 2 indicate the most pronounced results from seed dipped in a 6-percent solution of ethylene chlorhydrin and held in a

closed container from 36 to 48 hours. Seed dipped in a 1-percent solution of sodium thiocyanate and held in tight containers for 24, 36, and 48 hours, also those dipped in a 2-percent solution of the above chemical and held in tight containers for 6, 12, 18, and 24 hours gave nearly as good results as those in the 6-percent ethylene chlorhydrin treatment. Seed gassed for 12 hours with 5 cc of ethylene chlorhydrin per liter of container space showed the highest percentage of germination in 15 days. Considerable foliage injury was noted in plants produced from seed dipped in a 3-percent sodium-thiocyanate solution and then held in closed containers for periods of 6, 12, 18, and 24 hours. This treatment also delayed germination.

TABLE 2.—*Germination results obtained with Irish Cobbler seed pieces treated with chemicals to break the rest period*

[Treated Nov. 27, planted Nov. 30, 1928]

| Treatmen | Duration of treatment | Rate of germination in— | | | | |
|---|---|---|---|---|---|---|
| | | 15 days | 17 days | 19 days | 26 days | 31 days |
| | *Hours* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Seed dipped in a 4-percent solution of ethylene chlorhydrin, then put in tight container for periods stated | 24 | ..... | 15 | 50 | 85 | 95 |
| | 36 | ..... | 10 | 20 | 75 | 80 |
| | 48 | 5 | 40 | 75 | 90 | 90 |
| Seed dipped in a 6-percent solution of ethylene chlorhydrin, then put in a tight container for periods stated | 24 | 10 | 80 | 90 | 95 | 95 |
| | 36 | 5 | 85 | 90 | 100 | ..... |
| | 48 | ..... | 90 | 85 | 100 | ..... |
| Seed gassed in a tight jar with 1 cc per quart of ethylene chlorhydrin for periods stated | 6 | ..... | 5 | 15 | 45 | 60 |
| | 12 | ..... | 15 | 45 | 60 | 95 |
| | 18 | ..... | 15 | 55 | 85 | 95 |
| | 24 | ..... | 40 | 50 | 75 | 80 |
| Seed gassed in a tight jar with 2 cc per quart of ethylene chlorhydrin for periods stated | 6 | ..... | 5 | 25 | 50 | 65 |
| | 12 | ..... | 30 | 75 | 95 | 95 |
| | 18 | ..... | 10 | 45 | 85 | 90 |
| | 24 | ..... | 30 | 60 | 70 | 85 |
| Seed gassed in a tight jar with 5 cc of ethylene chlorhydrin for periods stated | 6 | ..... | 45 | 75 | 90 | 90 |
| | 12 | 15 | 55 | 80 | 95 | 100 |
| Seed dipped in a 1-percent solution of sodium thiocyanate, then put in a tight container for periods stated | 24 | ..... | 40 | 80 | 100 | ..... |
| | 36 | ..... | 60 | 80 | 90 | 100 |
| | 48 | ..... | 30 | 75 | 95 | 100 |
| Seed dipped in a 2-percent solution of sodium thiocyanate, then put in a tight container for periods stated | 6 | ..... | ..... | 25 | 85 | 95 |
| | 12 | 5 | 35 | 60 | 95 | 100 |
| | 18 | 5 | 55 | 70 | 100 | ..... |
| | 24 | 5 | 55 | 75 | 95 | 95 |
| Seed dipped in a 3-percent solution of sodium thiocyanate, then put in a tight container for periods stated | 6 | ..... | ..... | 25 | 55 | [1] 90 |
| | 12 | ..... | 5 | 15 | 85 | [1] 95 |
| | 18 | ..... | ..... | 5 | 70 | [1] 85 |
| | 24 | ..... | ..... | 10 | 65 | [1] 80 |
| Check held in tight container | 48 | ..... | ..... | 5 | 35 | 45 |
| Check, freshly cut seed | ..... | ..... | ..... | 20 | 65 | 90 |
| Check dipped in water | 48 | ..... | ..... | 15 | 45 | 75 |

[1] Considerable injury to plants.

The first experiment, which is recorded in table 1, showed that the Dakota Red did not respond to the ethylene-chlorhydrin treatment, at least not during the 28-day observation period. On this account it was thought desirable to conduct further studies with it. Twenty lots of seed of this variety were treated December 18, as indicated in table 3. The concentrations of ethylene chlorhydrin and sodium thiocyanate were similar to those employed in the case of the Irish Cobbler, as were also the periods of exposure. It will be noted from the data in table 3 that very different results were obtained from those recorded in table 1 for the lot treated 36 days earlier. For comparison with the seed pieces treated in a similar manner December 18, the seed pieces treated November 12 were dipped in a 4-percent

ethylene-chlorhydrin solution and subsequently exposed to the gas in a tight container for 24 hours. It was found that the earlier treatment showed no response in 28 days, whereas in the later treatment 100-percent germination was secured in 27 days. It is interesting to note also that the check did not show any germination on this date, and it was not until 6 days later, or 33 days from the planting of the seed, that the freshly cut seed showed a 5-percent germination, while that cut and held 48 hours in a tight container had a 20-percent count.

Apparently there was some retardation due to the 48-hour treatment of seed dipped in a 4-percent solution of ethylene chlorhydrin. In the case of the 6-percent solution it is apparent that the 12-hour exposure was not so effective as the 24-, 36-, or 48-hour treatments. The 36-hour exposure was the most effective. Gassing the seed with 1, 2, or 5 cc of ethylene chlorhydrin per quart jar was much less effective than dipping and gassing combined and resulted in an appreciable percentage of decayed seed.

TABLE 3.—*Germination results obtained with Dakota Red seed pieces treated with chemicals to break the rest period*

[Treated Dec. 18, planted Dec. 20, 1928]

| Treatment | Duration of treatment | Rate of germination in— | | | | | Decayed seed |
|---|---|---|---|---|---|---|---|
| | | 15 days | 18 days | 21 days | 27 days | 33 days | |
| | *Hours* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* | *Per cent* |
| Seed dipped in a 4-percent solution of ethylene chlorhydrin, then put in a tight jar for periods stated | 24 | 30 | 60 | 70 | 100 | ------- | ------- |
| | 48 | ------- | 25 | 60 | 95 | 100 | ------- |
| Seed dipped in a 6-percent solution of ethylene chlorhydrin, then put in a tight jar for periods stated | 12 | 5 | 20 | 35 | 65 | 85 | ------- |
| | 24 | 60 | 75 | 90 | 95 | ------- | ------- |
| | 36 | 60 | 95 | 100 | ------- | ------- | ------- |
| | 48 | 50 | 70 | 80 | 90 | 95 | ------- |
| Seed gassed with 1 cc of ethylene chlorhydrin per quart in a tight jar for periods stated | 24 | 20 | 25 | ------- | 35 | 45 | 30 |
| | 48 | 10 | 30 | 45 | 50 | ------- | 45 |
| Seed gassed with 2 cc of ethylene chlorhydrin per quart in a tight jar for periods stated | 12 | 5 | 25 | 50 | 60 | 65 | 5 |
| | 24 | 15 | 45 | 55 | 60 | ------- | 35 |
| | 48 | ------- | 10 | 20 | 35 | ------- | 65 |
| Seed gassed with 5 cc ethylene chlorhydrin per quart in a tight jar for periods stated | 12 | ------- | 25 | 40 | 60 | 70 | 25 |
| | 24 | ------- | 15 | 30 | 75 | 80 | 20 |
| Seed dipped in a 1-percent solution of sodium thiocyanate, then put in a tight jar for periods stated | 24 | 5 | 60 | 85 | 90 | 100 | ------- |
| | 36 | 15 | 80 | 95 | 100 | ------- | ------- |
| | 48 | 10 | 65 | 80 | 95 | 100 | ------- |
| Seed dipped in a 2-percent solution of sodium thiocyanate, then put in a tight jar for periods stated | 12 | ------- | 60 | 90 | 100 | ------- | ------- |
| | 24 | ------- | 35 | 65 | 100 | ------- | ------- |
| | 36 | ------- | 10 | 65 | 100 | ------- | ------- |
| | 48 | ------- | 40 | 60 | 100 | ------- | ------- |
| Check seed, cut at same time as the others and held in a tight jar for period stated | 48 | ------- | ------- | ------- | ------- | 20 | ------- |
| Check, freshly cut seed | ------- | ------- | ------- | ------- | ------- | 5 | ------- |

Seed dipped in 1- and 2-percent sodium-thiocyanate solutions and held in closed containers for varying periods was a little slower to germinate than seed dipped in ethylene chlorhydrin. However, the development of the seed given the 1-percent treatment soon equaled that of the ethylene chlorhydrin. The 2-percent sodium-thiocyanate treatment gave the most uniform results.

### SEASON OF 1929–30

As in the previous season, the potatoes used in the 1929–30 chemical-treatment studies were grown at Presque Isle, Maine, and were harvested September 25.

| | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Do. | do. | do. | 2 | 1.5 | | | | | | | 33 |
| Untreated. | | do. | | | | | | | | | 7 |

[1] High temperature throughout period of treatment.
[2] Second lot of Early Rose.

From the information obtained in the 1928–29 studies it seemed desirable to determine the relative merits of the ethylene-chlorhydrin and sodium-thiocyanate treatments for hastening germination of potato tubers during their rest period. A method requiring gassing the sets in a closed container for a period of from 6 to 48 hours seemed obviously impracticable for commercial adoption and use. It was felt that if a method of soaking which would be approximately as effective as the dipping-gassing method could be developed the treating process would be greatly simplified. As such a method of soaking had been employed by Denny (*4*), his work paved the way for further study, and the 1929–30 treatments were definitely planned to permit careful study of the possibilities of the soaking method. Inasmuch as in previous studies sets dipped in a 6-percent solution of ethylene chlorhydrin and held in a closed container for 24 hours had given satisfactory results, this treatment was used as a standard of comparison with results obtained from sets soaked for varying intervals in different strengths of sodium thiocyanate.

Eight lots of 30 sets each of 23 varieties were treated as follows:

Lot 1.—Dipped in a 6-percent solution of ethylene chlorhydrin and gassed 24 hours.
Lot 2.—Soaked in a 1-percent solution of sodium thiocyanate 1 hour.
Lot 3.—Soaked in a 1½-percent solution of sodium thiocyanate 1 hour.
Lot 4.—Soaked in a 2-percent solution of sodium thiocyanate 1 hour.
Lot 5.—Soaked in a 1-percent solution of sodium thiocyanate 1½ hour.
Lot 6.—Soaked in a 1½-percent solution of sodium thiocyanate 1½ hours.
Lot 7.—Soaked in a 2-percent solution of sodium thiocyanate 1½ hours.
Lot 8.—Check (untreated).

The lots soaked in the sodium-thiocyanate solution were treated at the same time as those that were dipped in the ethylene-chlorhydrin solution and were planted in an Arlington Farm greenhouse the following day, as was also the dipped-gassed lot. The results obtained from the treatment of the 23 varieties are presented in table 4.

A study of these data indicates considerable variability in the response of different varieties to the chemical treatments. It is also apparent that some sets were rather seriously injured by the treatment. This is particularly true of those treated October 31 and November 1, the germination percentage of which is given in table 4. The injury was directly attributable to high day and night temperatures, which prevailed during treatment and subsequent planting. The most serious injury was to seed treated with ethylene chlorhydrin and held 24 hours in a tight container. Comparatively little injury was sustained in the case of lots soaked in the sodium-thiocyanate solutions except in the case of the 1½- and 2-percent solutions, especially during the longer treatments.

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The varieties involved in the hot-weather treatment period, October 31 to November 2, were Adirondack, American Giant, Early Rose, and Green Mountain. The results of the experiment serve to corroborate those obtained by Denny (*5*) in the treatment of potatoes during extremely hot weather.

Exclusive of the 4 varieties injured by high temperatures in the process of treatment during the dates mentioned, the following varieties responded most promptly: Burbank, Charles Downing, Early Manistee, Early Ohio, Early Rose treated November 12 and 13, Early St. George, Dakota Red, McCormick, Noroton Beauty, Northern Spy, Prolific, Queen-of-the-Valley, and White Ohio. A more critical analysis of these data indicates that 93 percent of the Prolific sets treated with ethylene chlorhydrin germinated in 16 days. White Ohio showed 90-percent germination in 23 days and Early Manistee and Early St. George 83 percent each in 17 days.

The most successful treatments in 1929, based on promptness of germination of treated seed as compared with untreated sets as presented in table 5, indicate that in two cases the untreated seed did not show any germination at the end of 36 and 37 days, while during the same period the treated seed gave a germination of 93 and 99.1 percent, respectively.

TABLE 5.—*Physiological responses of potato sets to chemical treatments, 1929–30*

| Variety | Days from treatment | Average germination from all treatments | Germination from untreated sets | Variety | Days from treatment | Average germination from all treatments | Germination from untreated sets |
|---|---|---|---|---|---|---|---|
| | *Number* | *Percent* | *Percent* | | *Number* | *Percent* | *Percent* |
| Charles Downing | 34 | 87.4 | 12 | Early Manistee | 36 | 77.1 | 43 |
| Dakota Red | 34 | 86.6 | 7 | Queen-of-the-Valley | 37 | 99.1 | 0 |
| White Ohio | 36 | 93.0 | 0 | Northern Spy | 37 | 78.9 | 17 |

Table 6, consisting of data compiled from table 4, indicates the time between treatment of tuber sets and the resultant 90-percent germination, in comparison with untreated sets. Where a lower percentage of germination is recorded, either the maximum percentage is indicated or the maximum percentage recorded during the total period of observation. In a number of instances where less than 100 percent is recorded, complete germination was attained a few days later.

A comparison of the relative germination of treated and untreated potato sets reveals that those of Beauty of Hebron, Early St. George, Queen-of-the-Valley, and White Ohio, which were treated with ethylene chlorhydrin, showed a germination of 90 percent or over before any sign of germination was noted in the untreated sets. The time intervals were 24, 22, 26, and 23 days, respectively. Early Manistee, Dakota Red, and the White-Eyed Peachblow gave 93, 90, and 100 percent germination in 22, 31, and 21 days, respectively, from the sets treated with ethylene chlorhydrin, as against 3, 7, and 7 percent germination from the untreated sets.

Nine of the nineteen varieties showed a quicker response from the ethylene-chlorhydrin treatment as against 3 varieties giving quicker germination from the sodium-thiocyanate treatment, while the remaining 7 showed the same acceleration from one or more of the sodium-thiocyanate concentration or time treatments as from ethylene chlorhydrin.

TABLE 6.—*Percentage of germination of potato sets and number of days required after chemical treatment to reach 90 percent or over*[1] *and resultant germination of untreated sets during the 1929–30 season*

| Variety | Germination when treated with— | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ethylene chlorhydrin | | | Sodium thiocyanate | | | | | | | | | | | | | | | | | |
| | 6 percent for 24 hours | | Check | 1 percent for 1 hour | | Check | 1.5 percent for 1 hour | | Check | 2 percent for 1 hour | | Check | 1 percent for 1.5 hours | | Check | 1.5 percent for 1.5 hours | | Check | 2 percent for 1.5 hours | | Check |
| | *Days* | *Pct.* | *Pct.* | *Days* | *Pct.* | *Pct.* | *Days* | *Pct.* | *Pct.* | *Days* | *Pct.* | *Pct.* | *Days* | *Pct.* | *Pct.* | *Days* | *Pct.* | *Pct.* | *Days* | *Pct.* | *Pct.* |
| Beauty of Hebron | 24 | 93 | 0 | 32 | 90 | 30 | 36 | 97 | 77 | 36 | 87 | 77 | 32 | 93 | 30 | 32 | 80 | 30 | 36 | 67 | 77 |
| Burbank | 29 | 90 | 47 | 41 | 87 | 87 | 29 | 80 | 47 | 41 | 73 | 87 | 23 | 97 | 7 | 29 | 83 | 47 | 32 | 77 | 53 |
| Charles Downing | 31 | 96 | 8 | 31 | 96 | 8 | 39 | 84 | 28 | 34 | 100 | 12 | 31 | 100 | 8 | 39 | 92 | 28 | 39 | 64 | 28 |
| Early Manistee | 22 | 93 | 3 | 48 | 83 | 93 | 48 | 83 | 93 | 48 | 97 | 93 | 28 | 93 | 17 | 48 | 93 | 93 | 48 | 90 | 93 |
| Early Ohio | 31 | 90 | 17 | 31 | 93 | 17 | 37 | 97 | 50 | 37 | 93 | 50 | 37 | 100 | 50 | 37 | 93 | 50 | 37 | 44 | 50 |
| Early Rose [2] | 26 | 90 | 80 | 35 | 83 | 93 | 35 | 77 | 93 | 38 | 67 | 93 | 35 | 83 | 93 | 35 | 73 | 93 | 35 | 67 | 93 |
| Early St. George | 22 | 90 | 0 | 28 | 93 | 10 | 36 | 93 | 67 | 48 | 83 | 87 | 36 | 97 | 67 | 36 | 93 | 67 | 36 | 97 | 67 |
| Dakota Red | 31 | 90 | 7 | 31 | 97 | 7 | 39 | 90 | 10 | 39 | 80 | 10 | 34 | 90 | 7 | 46 | 90 | 30 | 39 | 87 | 10 |
| Keeper | 21 | 88 | 20 | 25 | 92 | 20 | 30 | 96 | 44 | 30 | 88 | 44 | 25 | 92 | 20 | 25 | 92 | 20 | 30 | 92 | 44 |
| McCormick | 27 | 90 | 17 | 50 | 90 | 67 | 50 | 83 | 67 | 50 | 53 | 67 | 45 | 90 | 60 | 45 | 73 | 60 | 50 | 60 | 67 |
| Noroton Beauty | 32 | 90 | 77 | 32 | 90 | 77 | 32 | 90 | 77 | 36 | 93 | 87 | 32 | 97 | 77 | 32 | 93 | 77 | 36 | 97 | 87 |
| Northern Spy | 49 | 80 | 20 | 49 | 87 | 20 | 37 | 93 | 17 | 49 | 90 | 20 | 49 | 83 | 20 | 37 | 87 | 17 | 49 | 73 | 20 |
| Prolific | 16 | 93 | 13 | 30 | 97 | 70 | 30 | 90 | 70 | 45 | 90 | 100 | 30 | 97 | 70 | 35 | 93 | 90 | 45 | 83 | 100 |
| Queen-of-the-Valley | 26 | 90 | 0 | 26 | 97 | 0 | 31 | 97 | 0 | 31 | 97 | 0 | 31 | 93 | 0 | 31 | 90 | 0 | 37 | 100 | 0 |
| Scotch Rose | 33 | 93 | 20 | 30 | 97 | 7 | 38 | 97 | 27 | 38 | 90 | 27 | 33 | 93 | 20 | 38 | 97 | 27 | 42 | 90 | 70 |
| White-Eyed Peachblow | 21 | 100 | 7 | 27 | 90 | 13 | 32 | 100 | 33 | 32 | 97 | 33 | 27 | 100 | 13 | 32 | 90 | 33 | 32 | 97 | 33 |
| White Ohio | 23 | 90 | 0 | 33 | 100 | 0 | 33 | 97 | 0 | 36 | 87 | 0 | 33 | 100 | 0 | 33 | 90 | 0 | 36 | 70 | 0 |
| White Rose | 35 | 90 | 80 | 35 | 97 | 80 | 35 | 93 | 80 | 47 | 93 | 93 | 39 | 93 | 87 | 47 | 87 | 93 | 47 | 93 | 93 |
| White Star | 31 | 90 | 37 | 34 | 90 | 43 | 39 | 90 | 57 | 46 | 73 | 70 | 31 | 90 | 37 | 34 | 87 | 43 | 46 | 90 | 70 |
| Average | 27.9 | 90.8 | 23.8 | 34.1 | 92.1 | 39.0 | 36.1 | 90.9 | 49.3 | 40.0 | 85.8 | 55.3 | 33.2 | 93.7 | 35.9 | 36.4 | 88.2 | 47.3 | 39.6 | 80.9 | 55.5 |

[1] Whenever less than 90 percent is recorded the figure represents the maximum germination within the total period of observation of either the treated or check lots.
[2] Early Rose treated Nov. 12, 1929.

Perhaps one of the most interesting results is found in the reaction of Prolific in which the ethylene-chlorhydrin treated sets gave 93 percent germination in 16 days, while the check lot showed 13 percent germination. This would seem to indicate that the Prolific variety has a relatively short rest period. Other examples of a comparatively short rest period are found in Early Rose (second lot), Noroton Beauty, White Rose, Burbank, and White Star. The data presented in these instances indicate the desirability of determining the relative length of the rest period of the leading commercial varieties of potatoes. When the average time interval is compared for the different treatments of the 19 varieties, it is found that the 6-percent ethylene-chlorhydrin treated sets required the shortest period of days, 27.9, as compared with 33.2 days in the case of those treated 1½ hours in a 1-percent sodium-thiocyanate solution, which was the next shortest time interval to give 90 percent, or approximately 90 percent, germination.

SEASON OF 1930-31

In the 1930–31 studies 11 varieties were used. The sodium-thiocyanate treatments were restricted to a 1-hour soaking in 1- and 1½-percent solutions and a 1½-hour immersion in a 1-percent solution. Further modification consisted in a substitution of a 4-percent solution for a 6-percent solution of ethylene chlorhydrin for general comparison with the sodium-thiocyanate treatments. In three instances a 6-percent ethylene-chlorhydrin solution was used for comparison with the 4-percent solution.

The varieties American Giant, Beauty of Hebron, Burbank (Low-top), Early Ohio, Dakota Red, and Prolific were harvested September 8, 1930, and the Green Mountain, Irish Cobbler, Queen-of-the-Valley, Rural New Yorker No. 2, and Triumph on September 22. All of the varieties were grown at Aroostook Farm, Presque Isle, Maine.

The data in table 7 represent the calendar order of treatment of the several varieties.

These figures indicate a decided hastening of germination as compared with the checks of the varieties Rural New Yorker No. 2, American Giant, Burbank (Low-top), Green Mountain, Queen-of-the-Valley, Early Ohio, Dakota Red, and Triumph.

The data on the comparative efficacy of the ethylene-chlorhydrin and sodium-thiocyanate treatments as indicated in table 7 show that the 6-percent ethylene-chlorhydrin treatment resulted in a quicker germination response than the 4-percent treatment. Comparison of the response from the 4-percent ethylene-chlorhydrin treatment and the 1-percent 1-hour sodium-thiocyanate treated seed shows a decidedly quicker response in 6 of the 11 lots and somewhat greater in 2 other lots.

TABLE 7.—*Varietal responses of potato seed pieces treated with chemicals to break the rest period, 1930*

| Variety and chemical used | Date treated | Date planted | Concentration | Time of treatment | Rate of germination in— | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 15 days | 16 days | 17 days | 18 days | 19 days | 20 days | 21 days | 22 days | 23 days | 24 days | 25 days | 26 days | 27 days | 28 days | 29 days | 30 days |
| Irish Cobbler: | | | *Percent* | *Hours* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Ethylene chlorhydrin | Oct. 27 | Oct. 28 | 6 | [1] 24 | | | | | | 97 | | | 100 | | | | | | | |
| Do | do | do | 4 | [1] 24 | | | | | | 87 | | | 100 | | | | | | | |
| Sodium thiocyanate | do | do | 1 | 1 | | | | | | 70 | | | 80 | | | 90 | | 90 | | |
| Do | do | do | 1.5 | 1 | | | | | | 43 | | | 67 | | | 73 | | 77 | | |
| Do | do | do | 1 | 1.5 | | | | | | 33 | | | 70 | | | 83 | | 93 | | |
| Untreated | | do | | | | | | | | 13 | | | 27 | | | 43 | | 50 | | |
| Triumph: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 28 | Oct. 29 | 6 | [1] 24 | | 7 | | | 90 | | | 100 | | | | | | | | |
| Do | do | do | 4 | [1] 24 | | 3 | | | 47 | | | 90 | | | 100 | | | | | |
| Sodium thiocyanate | do | do | 1 | 1 | | | | | 30 | | | 43 | | | 70 | | | | | 100 |
| Do | do | do | 1.5 | 1 | | | | | 10 | | | 23 | | | 43 | | | | | 70 |
| Do | do | do | 1 | 1.5 | | | | | 17 | | | 63 | | | 83 | | | | | 100 |
| Untreated | | do | | | | | | | | | | 3 | | | 3 | | | | | 13 |
| Rural New Yorker No. 2: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 28 | do | 6 | [1] 24 | | 3 | | | 53 | | | 70 | | | 83 | | | | | 90 |
| Do | do | do | 4 | [1] 24 | | 7 | | | 40 | | | 47 | | | 50 | | | | | 60 |
| Sodium thiocyanate | do | do | 1 | 1 | | 3 | | | 37 | | | 40 | | | 50 | | | | | 57 |
| Do | do | do | 1.5 | 1 | | | | | 13 | | | 20 | | | 20 | | | | | 30 |
| Do | do | do | 1 | 1.5 | | | | | 3 | | | 33 | | | 43 | | | | | 50 |
| Untreated | | do | | | | | | | 3 | | | 3 | | | 3 | | | | | 3 |
| Early Ohio: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 29 | Oct. 30 | 4 | [1] 24 | | | | | | | 13 | | | 23 | | | | | 37 | |
| Sodium thiocyanate | do | do | 1 | 1 | | | | | | | 3 | | | 3 | | | | | 20 | |
| Do | do | do | 1.5 | 1 | | | | | | | | | | 13 | | | | | 20 | |
| Do | do | do | 1 | 1.5 | | | | | | | | | | 7 | | | | | 20 | |
| Untreated | | do | | | | | | | | | | | | | | | | | | |
| Beauty of Hebron: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 29 | do | 4 | [1] 24 | | | | | | | 50 | | | 57 | | | | | 67 | |
| Sodium thiocyanate | do | do | 1 | 1 | | | | | | | 10 | | | 13 | | | | | 53 | |
| Do | do | do | 1.5 | 1 | | | | | | | 7 | | | 23 | | | | | 40 | |
| Do | do | do | 1 | 1.5 | | | | | | | 10 | | | 20 | | | | | 47 | |
| Untreated | | do | | | | | | | | | | | | 10 | | | | | 13 | |
| Green Mountain: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 30 | Oct. 31 | 4 | [1] 24 | | | 20 | | | 20 | | | 27 | | | | | 57 | | |
| Sodium thiocyanate | do | do | 1 | 1 | | | 10 | | | 27 | | | 67 | | | | | 90 | | |
| Do | do | do | 1.5 | 1 | | | 7 | | | 17 | | | 43 | | | | | 70 | | |
| Do | do | do | 1 | 1.5 | | | | | | 17 | | | 53 | | | | | 83 | | |
| Untreated | | do | | | | | | | | | | | 3 | | | | | 7 | | |

[1] Dipped and then confined in a tight container for time indicated.

TABLE 7.—*Varietal responses of potato seed pieces treated with chemicals to break the rest period, 1930*—Continued

| Variety and chemical used | Date treated | Date planted | Concentration | Time of treatment | Rate of germination in— | | | | | | | | | | | | | | Decayed seed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 31 days | 32 days | 33 days | 34 days | 35 days | 36 days | 37 days | 38 days | 39 days | 40 days | 41 days | 42 days | 43 days | 44 days | |
| Irish Cobbler: | | | *Percent* | *Hours* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Percent* |
| Ethylene chlorhydrin | Oct. 28 | Oct. 28 | 6 | [1] 24 | | | | | | | | | | | | | | | |
| Do | do | do | 4 | [1] 24 | | | | | | | | | | | | | | | |
| Sodium thiocyanate | do | do | 1 | 1 | 100 | | | | | | | | | | | | | | |
| Do | do | do | 1.5 | 1 | 87 | | | 90 | | | 100 | | | | | | | | |
| Do | do | do | 1 | 1.5 | 97 | | | 97 | | | | | | | | | | | 0 |
| Untreated | | do | | | 57 | | | 70 | | | 70 | | | | | | | | 7 |
| Triumph: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 28 | Oct. 29 | 6 | [1] 24 | | | | | | | | | | | | | | | |
| Do | do | do | 4 | [1] 24 | | | | | | | | | | | | | | | |
| Sodium thiocyanate | do | do | 1 | 1 | | | | | | | | | | | | | | | |
| Do | do | do | 1.5 | 1 | | | 83 | | | 100 | | | | | | | | | |
| Do | do | do | 1 | 1.5 | | | | | | | | | | | | | | | |
| Untreated | | do | | | | | 20 | | | 20 | | | | | | | | | 20 |
| Rural New Yorker No. 2: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 28 | do | 6 | [1] 24 | | | 97 | | | 97 | | | | | | | | | 0 |
| Do | do | do | 4 | [1] 24 | | | 63 | | | 80 | | | | | | | | | 0 |
| Sodium thiocyanate | do | do | 1 | 1 | | | 70 | | | 70 | | | | | | | | | 0 |
| Do | do | do | 1.5 | 1 | | | 50 | | | 70 | | | | | | | | | 0 |
| Do | do | do | 1 | 1.5 | | | 77 | | | 77 | | | | | | | | | 0 |
| Untreated | | do | | | | | 3 | | | 3 | | | | | | | | | 0 |
| Early Ohio: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 29 | Oct. 30 | 4 | [1] 24 | | | | | 63 | | | | 73 | | | 83 | | 90 | 10 |
| Sodium thiocyanate | do | do | 1 | 1 | | | | | 43 | | | | 80 | | | 83 | | 100 | |
| Do | do | do | 1.5 | 1 | | | | | 43 | | | | 80 | | | 87 | | 100 | |
| Do | do | do | 1 | 1.5 | | | | | 50 | | | | 80 | | | 90 | | 100 | |
| Untreated | | do | | | | | | | 3 | | | | 3 | | | 7 | | 13 | 0 |
| Beauty of Hebron: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 29 | do | 4 | [1] 24 | | | | | 80 | | | | 80 | | | 90 | | 93 | 7 |
| Sodium thiocyanate | do | do | 1 | 1 | | | | | 77 | | | | 97 | | | 100 | | | |
| Do | do | do | 1.5 | 1 | | | | | 53 | | | | 70 | | | 87 | | 100 | |
| Do | do | do | 1 | 1.5 | | | | | 63 | | | | 83 | | | 87 | | 100 | |
| Untreated | | do | | | | | | | 23 | | | | 33 | | | 40 | | 53 | 0 |
| Green Mountain: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Oct. 30 | Oct. 31 | 4 | [1] 24 | | | | 83 | | | | 83 | | | 90 | | | | 0 |
| Sodium thiocyanate | do | do | 1 | 1 | | | | 93 | | | | 97 | | | 100 | | | | |
| Do | do | do | 1.5 | 1 | | | | 90 | | | | 100 | | | | | | | |
| Do | do | do | 1 | 1.5 | | | | 100 | | | | | | | | | | | |
| Untreated | | do | | | | | | 7 | | | | 10 | | | 10 | | | | 7 |

[1] Dipped and then confined in a tight container for time indicated.

| Variety and chemical used | Date treated | Date planted | Concentration | Time of treatment | Rate of germination in— | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 15 days | 16 days | 17 days | 18 days | 19 days | 20 days | 21 days | 22 days | 23 days | 24 days | 25 days | 26 days | 27 days | 28 days | 29 days | 30 days |
| Burbank (Low-top): | | | *Percent* | *Hours* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Ethylene chlorhydrin | Oct. 30 | Oct. 31 | 4 | [1] 24 | | | 13 | | | 13 | | | 17 | | | | | 37 | | |
| Sodium thiocyanate | do | do | 1 | 1 | | | 7 | | | 7 | | | 37 | | | | | 70 | | |
| Do | do | do | 1.5 | 1 | | | 3 | | | 7 | | | 17 | | | | | 43 | | |
| Do | do | do | 1 | 1.5 | | | 10 | | | 13 | | | 30 | | | | | 77 | | |
| Untreated | | do | | | | | | | | | | | | | | | | | | |
| American Giant: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 4 | Nov. 5 | 4 | [1] 24 | 20 | | | 50 | | | | | 57 | | | | | | 73 | |
| Sodium thiocyanate | do | do | 1 | 1 | | | | 7 | | | | | 37 | | | | | | 77 | |
| Do | do | do | 1.5 | 1 | | | | | | | | | 17 | | | | | | 57 | |
| Do | do | do | 1 | 1.5 | | | | | | | | | 10 | | | | | | 50 | |
| Untreated | | do | | | | | | | | | | | | | | | | | | |
| Prolific: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 4 | do | 4 | [1] 24 | 3 | | | 23 | | | | | 63 | | | | | | 70 | |
| Sodium thiocyanate | do | do | 1 | 1 | | | | 3 | | | | | 27 | | | | | | 70 | |
| Do | do | do | 1.5 | 1 | | | | 3 | | | | | 13 | | | | | | 47 | |
| Do | do | do | 1 | 1.5 | 7 | | | 13 | | | | | 33 | | | | | | 70 | |
| Untreated | | do | | | | | | | | | | | 10 | | | | | | 20 | |
| Dakota Red: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 6 | Nov. 7 | 4 | [1] 24 | | 7 | | | | | 27 | | | 30 | | | 40 | | | |
| Sodium thiocyanate | do | do | 1 | 1 | | 3 | | | | | 17 | | | 43 | | | 70 | | | |
| Do | do | do | 1.5 | 1 | | 3 | | | | | 7 | | | 33 | | | 53 | | | |
| Do | do | do | 1 | 1.5 | | 10 | | | | | 20 | | | 37 | | | 57 | | | |
| Untreated | | do | | | | | | | | | | | | 3 | | | 3 | | | |
| Queen-of-the-Valley: | | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 6 | do | 4 | [1] 24 | | | | | | | | | | 17 | | | 17 | | | |
| Sodium thiocyanate | do | do | 1 | 1 | | 20 | | | | | 73 | | | 97 | | | 97 | | | |
| Do | do | do | 1.5 | 1 | | 3 | | | | | 37 | | | 67 | | | 73 | | | |
| Do | do | do | 1 | 1.5 | | 20 | | | | | 53 | | | 87 | | | 90 | | | |
| Untreated | | do | | | | | | | | | | | | 3 | | | 3 | | | |

[1] Dipped and then confined in a tight container for time indicated.

TABLE 7.—*Varietal responses of potato seed pieces treated with chemicals to break the rest period, 1930*—Continued

| Variety and chemical used | Date treated | Date planted | Concentration | Time of treatment | Rate of germination in— | | | | | | | | | | | | | Decayed seed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 31 days | 32 days | 33 days | 34 days | 35 days | 36 days | 37 days | 38 days | 39 days | 40 days | 41 days | 42 days | 43 days | 44 days | |
| Burbank (Low-top): | | | *Percent* | *Hours* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Percent* |
| Ethylene chlorhydrin | Oct. 30 | Oct. 31 | 4 | [1] 24 | | | | 53 | | | | 77 | | | 80 | | | | 0 |
| Sodium thiocyanate | do | do | 1 | 1 | | | | 77 | | | | 100 | | | | | | | |
| Do | do | do | 1.5 | 1 | | | | 70 | | | | 87 | | | 93 | | | | 0 |
| Do | do | do | 1 | 1.5 | | | | 97 | | | | | | | | | | | 3 |
| Untreated | | do | | | | | | 7 | | | | 10 | | | 10 | | | | 3 |
| American Giant: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 4 | Nov. 5 | 4 | [1] 24 | | | 93 | | | 97 | | 100 | | | | | | | |
| Sodium thiocyanate | do | do | 1 | 1 | | | 97 | | | 97 | | 100 | | | | | | | |
| Do | do | do | 1.5 | 1 | | | 80 | | | 83 | | 93 | | | | | | | 7 |
| Do | do | do | 1 | 1.5 | | | 83 | | | 97 | | 100 | | | | | | | |
| Untreated | | do | | | | | 3 | | | 7 | | 10 | | | | | | | 0 |
| Prolific: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 4 | do | 4 | [1] 24 | | | 80 | | | 83 | | 87 | | | | | | | 13 |
| Sodium thiocyanate | do | do | 1 | 1 | | | 97 | | | 100 | | | | | | | | | |
| Do | do | do | 1.5 | 1 | | | 80 | | | 80 | | 97 | | | | | | | 3 |
| Do | do | do | 1 | 1.5 | | | 90 | | | 100 | | | | | | | | | |
| Untreated | | do | | | | | 27 | | | 33 | | 60 | | | | | | | 0 |
| Dakota Red: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 6 | Nov. 7 | 4 | [1] 24 | 63 | | | 67 | | 67 | | | | | | | | | 3 |
| Sodium thiocyanate | do | do | 1 | 1 | 90 | | | 93 | | 100 | | | | | | | | | |
| Do | do | do | 1.5 | 1 | 87 | | | 90 | | 100 | | | | | | | | | |
| Do | do | do | 1 | 1.5 | 80 | | | 80 | | 90 | | | | | | | | | 10 |
| Untreated | | do | | | 10 | | | 13 | | 17 | | | | | | | | | 3 |
| Queen-of-the-Valley: | | | | | | | | | | | | | | | | | | | |
| Ethylene chlorhydrin | Nov. 6 | do | 4 | [1] 24 | 27 | | | 33 | | 60 | | | | | | | | | 0 |
| Sodium thiocyanate | do | do | 1 | 1 | 100 | | | | | | | | | | | | | | |
| Do | do | do | 1.5 | 1 | 90 | | | 90 | | 97 | | | | | | | | | 3 |
| Do | do | do | 1 | 1.5 | 100 | | | | | | | | | | | | | | |
| Untreated | | do | | | 3 | | | 7 | | 10 | | | | | | | | | 14 |

[1] Dipped and then confined in a tight container for time indicated.

The data presented in table 8 are a condensation of the final germination percentages recorded during the period of observation. These figures represent the end result, as it were, but do not indicate the rate of germination acceleration of the treated seed as compared with the checks or with different chemical solution concentrations and time intervals of treatment. The data do, however, serve to furnish the reader with a condensed summary of the results obtained. As has been previously mentioned, the 6-percent ethylene-chlorhydrin treatments show the greatest acceleration. Of the three varieties receiving such treatment the Triumph and Irish Cobbler show the most marked response. The former variety showed 90-percent germination in 19 days before the check sets showed any germination while the Irish Cobbler gave a 97-percent germination in 20 days, but at that time the check had shown a 13-percent germination. Apparently the tuber rest period of the Irish Cobbler is shorter or is more easily affected by chemical treatment than that of the Triumph. This is all the more evident in that the untreated Triumph sets did not show 13-percent germination until 30 days from date of starting the experiment. A similar comparison of the relative depth of rest period of the Rural New Yorker No. 2 variety shows that only 3-percent germination of the untreated sets occurred during the 36-day observation period. Another striking example of this sort is noted in the Early Ohio, Irish Cobbler, and Prolific in which the untreated sets of the first had only shown a 3-percent germination in 35 days, 7 percent in 42 days, and 13 percent in 44 days, whereas the Irish Cobbler check lot showed 70-percent germination in 34 days and the Prolific 60 percent in 38 days. These examples serve to indicate a distinct variability either in the length or depth of the rest period of different varieties of potatoes.

TABLE 8.—*Percentage of germination of potato sets and number of days required after chemical treatment to reach 90 percent or over* [1] *and resultant germination of untreated sets during the 1930–31 season*

| Variety | Germination when treated with— | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Ethylene chlorhydrin | | | | | | Sodium thiocyanate | | | | | | | | |
| | 6 percent for 24 hours | | Check | 4 percent for 24 hours | | Check | 1 percent for 1 hour | | Check | 1½ percent for 1 hour | | Check | 1 percent for 1½ hours | | Check |
| | *Dy.* | *Pct.* | *Pct.* | *Dy.* | *Pct.* | *Pct.* | *Dy.* | *Pct.* | *Pct.* | *Dy.* | *Pct.* | *Pct.* | *Dy.* | *Pct.* | *Pct.* |
| American Giant | ---- | ---- | ------- | 33 | 93 | 3 | 33 | 97 | 3 | 38 | 93 | 10 | 36 | 97 | 7 |
| Beauty of Hebron | ---- | ---- | ------- | 42 | 90 | 40 | 39 | 97 | 33 | 44 | 100 | 53 | 44 | 100 | 53 |
| Burbank (Low-top) | ---- | ---- | ------- | 41 | 80 | 10 | 38 | 100 | 10 | 41 | 93 | 10 | 34 | 97 | 7 |
| Early Ohio | ---- | ---- | ------- | 44 | 90 | 13 | 44 | 100 | 13 | 44 | 100 | 13 | 42 | 90 | 7 |
| Irish Cobbler | 20 | 97 | 13 | 23 | 100 | 27 | 26 | 90 | 43 | 34 | 90 | 70 | 28 | 93 | 50 |
| Dakota Red | ---- | ---- | ------- | 34 | 67 | 13 | 31 | 90 | 10 | 34 | 90 | 13 | 36 | 90 | 17 |
| Green Mountain | ---- | ---- | ------- | 41 | 90 | 10 | 28 | 90 | 7 | 34 | 90 | 7 | 34 | 100 | 7 |
| Prolific | ---- | ---- | ------- | 38 | 87 | 60 | 33 | 97 | 27 | 38 | 97 | 60 | 33 | 90 | 27 |
| Queen-of-the-Valley | ---- | ---- | ------- | 36 | 60 | 10 | 24 | 97 | 3 | 31 | 90 | 3 | 27 | 90 | 3 |
| Rural New Yorker No. 2 | 30 | 90 | 3 | 36 | 80 | 3 | 36 | 70 | 3 | 36 | 70 | 3 | 33 | 77 | 3 |
| Triumph | 19 | 90 | 0 | 22 | 90 | 3 | 30 | 100 | 13 | 36 | 100 | 20 | 30 | 100 | 13 |

[1] Wherever less than 90 percent is recorded, the figure represents the maximum germination within the total period of observation.

In a later trial made for the purpose of determining the best period of treatment with sodium thiocyanate three varieties were used, Green

Mountain, Irish Cobbler, and Triumph. The length of immersion was 1, 1½, and 2 hours in a 1-percent solution. Seed treated in this manner was compared with seed dipped in a 6-percent ethylene-chlorhydrin solution and confined in a tight container for 24 hours, and also with untreated seed.

The results, which are presented in table 9, corroborate the general behavior of previous treatments. Comparing the average germination of the three varieties, the ethylene chlorhydrin shows a 99-percent germination in 28.7 days, as against 98-, 99-, and 96.7-percent germination in 30, 30, and 32.7 days from the 1-, 1½-, and 2-hour treatments, and 62.3 percent in 32.7 days from the untreated seed.

Of the five varieties showing a final advantage from the sodium-thiocyanate treatments, the Burbank and Dakota Red are the most outstanding.

TABLE 9.—*Varietal responses of potato seed pieces treated with chemicals to break the rest period*

[Sets treated Dec. 2 and planted Dec. 3, 1930][1]

| Variety and chemical used | Concentration | Time of treatment | Rate of germination in— | | | | Decayed seed |
|---|---|---|---|---|---|---|---|
| | | | 20 days | 26 days | 30 days | 34 days | |
| Irish Cobbler: | *Percent* | *Hours* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Ethylene chlorhydrin | 6 | 24 | 17 | 80 | 100 | | |
| Sodium thiocyanate | 1 | 1 | 23 | 90 | 100 | | |
| Do | 1 | 1.5 | 7 | 83 | 100 | | |
| Do | 1 | 2 | 7 | 83 | 100 | | |
| Check | | | 7 | 13 | 37 | | 6 |
| Triumph: | | | | | | | |
| Ethylene chlorhydrin | 6 | 24 | 73 | 97 | | | 3 |
| Sodium thiocyanate | 1 | 1 | 20 | 93 | 97 | | 3 |
| Do | 1 | 1.5 | 10 | 80 | 97 | | 3 |
| Do | 1 | 2 | | 40 | 60 | 93 | 7 |
| Check | | | | 30 | 97 | 100 | |
| Green Mountain: | | | | | | | |
| Ethylene chlorhydrin | 6 | 24 | 3 | 90 | 100 | | |
| Sodium thiocyanate | 1 | 1 | 7 | 90 | 97 | | 3 |
| Do | 1 | 1.5 | 3 | 77 | 100 | | |
| Do | 1 | 2 | | 57 | 83 | 97 | 3 |
| Check | | | | 10 | 23 | 50 | 0 |

[1] The average percentage of germination under the various treatments was as follows: Ethylene chlorhydrin, 99 percent in 28.7 days; sodium thiocyanate, 98 percent in 30 days when seed pieces were treated 1 hour; 99 percent in 30 days when seed pieces were treated 1.5 hours; and 96.7 percent in 32.7 days when seed pieces were treated 2 hours. The untreated, or check, plot averaged 62.3 percent germination in 32.7 days.

### SUMMER AND FALL OF 1931

In order to secure additional information on the efficacy of ethylene-chlorhydrin gas in breaking the rest period of mature potatoes, 7 varieties grown at the Arlington Experiment Farm, which were harvested August 5 and held in a storage temperature of about 45° F., were gassed August 26 and 27. The concentration of the gas was at the rate of 1 cc per liter of air space, and the period of treatment was 24 hours. The lots treated consisted of whole and cut sets. One lot of whole tubers of each variety was dipped in water prior to treatment, while a second lot was treated dry. On removal from the airtight chamber they were held in a 60° F. storage room for 15 days, after which they were transferred to a storage room held at 70° F. until germination notes were completed. The data obtained are presented in table 10.

Wet-treated tubers of the Charles Downing variety germinated more promptly than any other lot. Four of the seven varieties showed quicker germination from the wet tubers than from dry-treated tubers, while in the case of the Burbank, Rural New Yorker No. 2, and Triumph the reverse was true. Some lots of cut seed showed decay as a result of injury from the treatment.[3]

Owing to scarcity of seed, it was possible to run checks only with the first three varieties.

TABLE 10.—*Ethylene chlorhydrin gas treatment of seven varieties of potatoes with 1 cc per liter of air space for 24 hours*

[Potatoes harvested Aug. 5 and treated Aug. 26–27, 1931]

| Variety and number of tubers | Whole or cut | Dry or wet | Rate of germination in— | | | | | | | | | | | Decay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 18 days | 21 days | 25 days | 29 days | 33 days | 36 days | 39 days | 43 days | 46 days | 50 days | 60 days | 74 days | |
| Irish Cobbler: | | | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. | Pct. |
| 25 | Whole | Dry | 24 | 36 | 40 | 60 | 60 | 72 | 72 | 84 | 100 | ---- | ---- | ---- | ---- |
| 25 | do | Wet | 56 | 84 | 84 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 25 | Cut [1] | Dry | 10 | 20 | 30 | 34 | 34 | 38 | 52 | ---- | ---- | ---- | ---- | ---- | 22 |
| 25 | Whole [2] | do | 0 | 0 | 0 | 0 | 0 | 4 | 24 | 44 | 96 | 100 | ---- | ---- | ---- |
| 25 | Whole [3] | do | 0 | 0 | 0 | 0 | 0 | 4 | 12 | 44 | 64 | 76 | 100 | ---- | ---- |
| Triumph: | | | | | | | | | | | | | | | |
| 25 | Whole | do | 28 | 56 | 68 | 92 | 96 | 96 | 96 | ---- | ---- | ---- | ---- | ---- | ---- |
| 25 | do | Wet | 52 | 76 | 84 | 92 | 92 | 92 | 96 | ---- | ---- | ---- | ---- | ---- | ---- |
| 25 | Cut [1] | Dry | 12 | 26 | 38 | 42 | 46 | 54 | 62 | ---- | ---- | ---- | ---- | ---- | 20 |
| 25 | Whole [2] | do | 4 | 4 | 4 | 24 | 36 | 52 | 60 | 68 | 76 | 92 | 100 | ---- | ---- |
| Early Ohio: | | | | | | | | | | | | | | | |
| 25 | Whole | do | 4 | 8 | 20 | 44 | 44 | 48 | 48 | 48 | 60 | 80 | 92 | 100 | ---- |
| 25 | do | Wet | 32 | 44 | 68 | 68 | 68 | 72 | 72 | 80 | 88 | 100 | ---- | ---- | ---- |
| 25 | Cut [1] | Dry | 2 | 2 | 6 | 22 | 24 | 28 | 38 | ---- | ---- | ---- | ---- | ---- | 32 |
| 25 | Whole [3] | do | 0 | 4 | 4 | 4 | 4 | 4 | 12 | 12 | 16 | 24 | 64 | 92 | 8 |
| Katahdin: | | | | | | | | | | | | | | | |
| 20 | Whole | do | 95 | 95 | 95 | 95 | 95 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 20 | do | Wet | 95 | 95 | 95 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 25 | Cut [1] | Dry | 36 | 50 | 56 | 72 | 72 | 78 | 78 | ---- | ---- | ---- | ---- | ---- | 12 |
| Charles Downing: | | | | | | | | | | | | | | | |
| 20 | Whole | do | 30 | 65 | 65 | 85 | 85 | 85 | 85 | 100 | ---- | ---- | ---- | ---- | ---- |
| 20 | do | Wet | 95 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| 25 | Cut [1] | Dry | 28 | 28 | 44 | 76 | 76 | 82 | 90 | ---- | ---- | ---- | ---- | ---- | 6 |
| Burbank: | | | | | | | | | | | | | | | |
| 20 | Whole | do | 25 | 35 | 40 | 70 | 70 | 75 | 95 | ---- | ---- | ---- | ---- | ---- | ---- |
| 20 | do | Wet | 65 | 65 | 85 | 85 | 90 | 90 | 90 | ---- | ---- | ---- | ---- | ---- | ---- |
| 25 | Cut [1] | Dry | 6 | 18 | 38 | 58 | 50 | 66 | 78 | ---- | ---- | ---- | ---- | ---- | 10 |
| Rural New Yorker No. 2: | | | | | | | | | | | | | | | |
| 20 | Whole | do | 75 | 80 | 80 | 85 | 85 | 95 | 95 | 95 | 100 | ---- | ---- | ---- | ---- |
| 20 | do | Wet | 85 | 90 | 90 | 90 | 90 | 90 | 90 | ---- | ---- | ---- | ---- | ---- | ---- |
| 25 | Cut [1] | Dry | 12 | 34 | 46 | 60 | 60 | 62 | 68 | ---- | ---- | ---- | ---- | ---- | 24 |

[1] No. 2 tubers cut in two.
[2] No. 1 tubers whole, untreated check.
[3] No. 2 tubers whole, untreated check.

On September 21 four lots each of Irish Cobbler and Triumph potatoes were treated with ethylene chlorhydrin at the rate of one half cc of the liquid to each liter of air space, or at the rate of slightly over 14 cc per cubic foot of air space. All lots consisted of whole tubers which had been harvested September 12. Two lots of each variety were gassed for 24 hours and the other 2 for 48 hours. In each pair of treatments one lot was thoroughly moistened before sacking. All were treated in burlap bags, in order to be comparable with car-lot treatment of sacked potatoes. The receptacle used was a galvanized-iron ash can, the cover of which was hermetically sealed with glaziers' putty. On removal of the tubers they were held at a room temperature of 70° F. for germination.

[3] The injury, when not severe enough to cause decay of the seed piece, was in the nature of retarded germination and a yellowing or bronzing of the foliage and terminal portion of the stem.

A study of the data presented in table 11 shows decided shortening of the rest period as compared with the check or untreated lot.

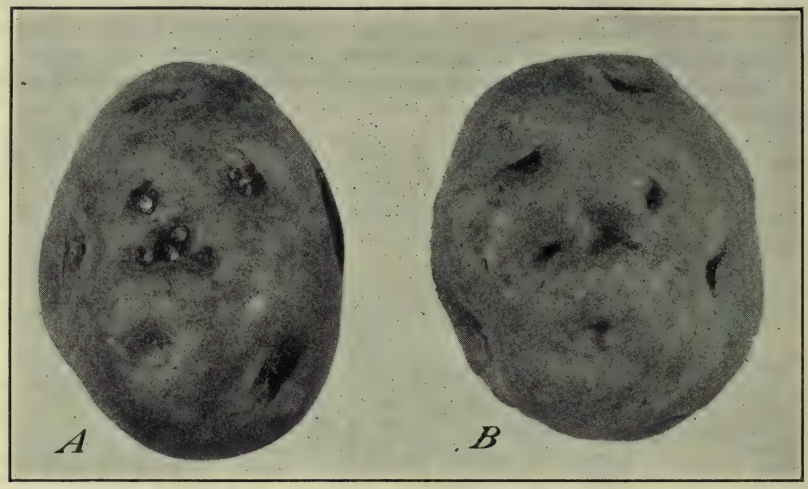


FIGURE 1.—Irish Cobbler potatoes: *A*, Treated September 21, 1931, in a 0.5-cc-per-liter concentration of ethylene chlorhydrin gas for 24 hours; *B*, tuber untreated. Photographed 13 days after treatment.

Slightly quicker germination was obtained from Triumph than from Irish Cobbler. The 24-hour exposure of the moistened lot of Triumphs and the 48-hour exposure of the dry lot showed 64 and 52

FIGURE 2.—Triumph potatoes receiving the same treatment as the Irish Cobblers in figure 1. Photographed 13 days after treatment.

percent of germinating tubers 14 days after treatment. The dry lot gave 100-percent germination in 21 days, against 25 days in the wet-lot treatment. No germination was noted in either check lot 29 days from treatment, while 3 days later each lot had 1 germinated

tuber. On the fifty-third day from treatment the check lot of Irish Cobbler tubers had given 100-percent germination, but the Triumph showed only 20 percent. Figures 1 and 2 show the stage of germination of the treated tubers 13 days after treatment. Figures 3 and 4 show, by graphs, the rate of germination of the Irish Cobbler and Triumph treated September 21.

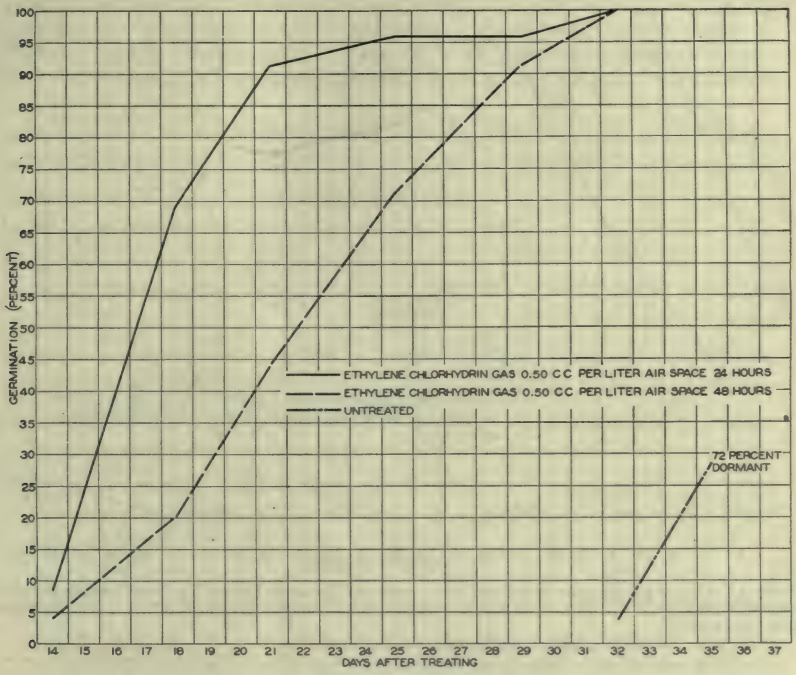
GERMINATION (PERCENT)
DAYS AFTER TREATING
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 24 HOURS
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 48 HOURS
UNTREATED
72 PERCENT DORMANT

FIGURE 3.—Rate of germination of treated and untreated Irish Cobbler tubers harvested September 12 and treated September 21–22, 1931, with ethylene chlorhydrin. Tubers placed in 70° F. room immediately after treatment.

TABLE 11.—*Ethylene chlorhydrin gas treatment with one half cc per liter of air space, using in each test 25 tubers of the Irish Cobbler and Triumph varieties*

[Potatoes harvested Sept. 12 and treated Sept. 21, 1931]

| Variety and condition of whole tuber | Duration of treatment | Rate of germination in— | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 14 days | 18 days | 21 days | 25 days | 29 days | 32 days | 35 days | 39 days | 42 days | 46 days | 49 days | 53 days | 60 days | 63 days | 67 days |
| Irish Cobbler: | *Hours* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Dry | 24 | ---- | 20 | 44 | 68 | 92 | 92 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Wet | 24 | 8 | 68 | 92 | 96 | 96 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Dry | 48 | ---- | 28 | 56 | 68 | 84 | 88 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Wet | 48 | 4 | 20 | 44 | 72 | 92 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Check | ---- | ---- | ---- | ---- | ---- | ---- | 4 | 28 | 52 | 72 | 84 | 96 | 100 | ---- | ---- | ---- |
| Triumph: | | | | | | | | | | | | | | | | |
| Dry | 24 | 24 | 48 | 76 | 92 | 96 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Wet | 24 | 64 | 88 | 96 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Dry | 48 | 52 | 96 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Wet | 48 | 16 | 56 | 72 | 88 | 96 | 100 | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- | ---- |
| Check | ---- | ---- | ---- | ---- | ---- | ---- | 4 | 8 | 8 | 8 | 8 | 8 | 20 | 64 | 80 | 92 |

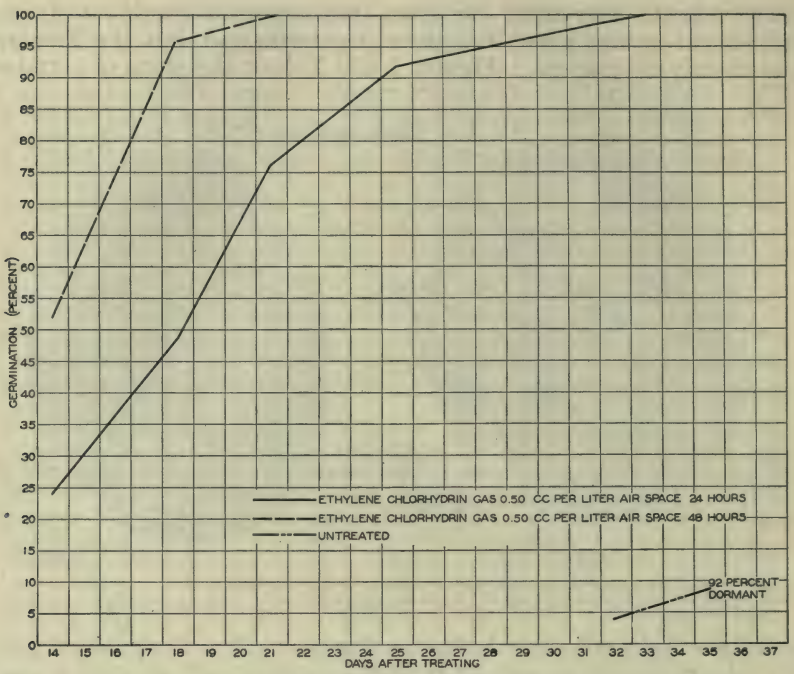
GERMINATION (PERCENT)
DAYS AFTER TREATING
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 24 HOURS
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 48 HOURS
UNTREATED
92 PERCENT DORMANT

FIGURE 4.—Rate of germination of treated and untreated Triumph tubers harvested September 12 and treated September 21–22, 1931, with ethylene chlorhydrin. Tubers placed in 70° F. room immediately after treatment.

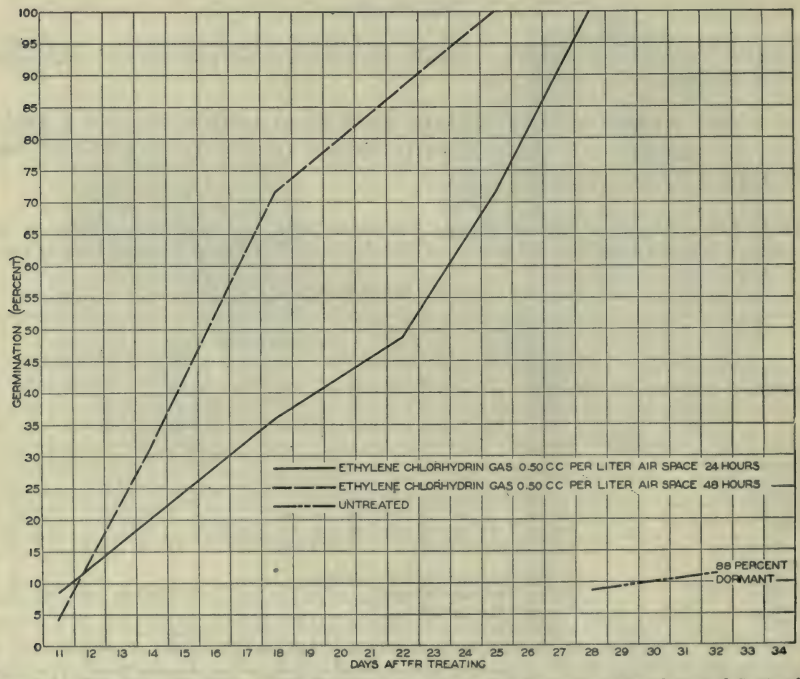
GERMINATION (PERCENT)
DAYS AFTER TREATING
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 24 HOURS
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 48 HOURS
UNTREATED
88 PERCENT DORMANT

FIGURE 5.—Rate of germination of Irish Cobbler tubers harvested September 12 and treated September 28–29, 1931, with ethylene chlorhydrin. Tubers placed in 70° F. room immediately after treatment.

The treatments of September 21 were repeated on the same varieties 1 week later. The results obtained, as presented in table 12, show that in 3 of the 4 Irish Cobbler comparative treatments the time interval between treatment and a 90-percent germination was shorter than in the September 21 treatment. A similar comparison of the Triumph data shows a 50–50 result. If, however, the average time interval between treatment and the 90-percent objective is compared,

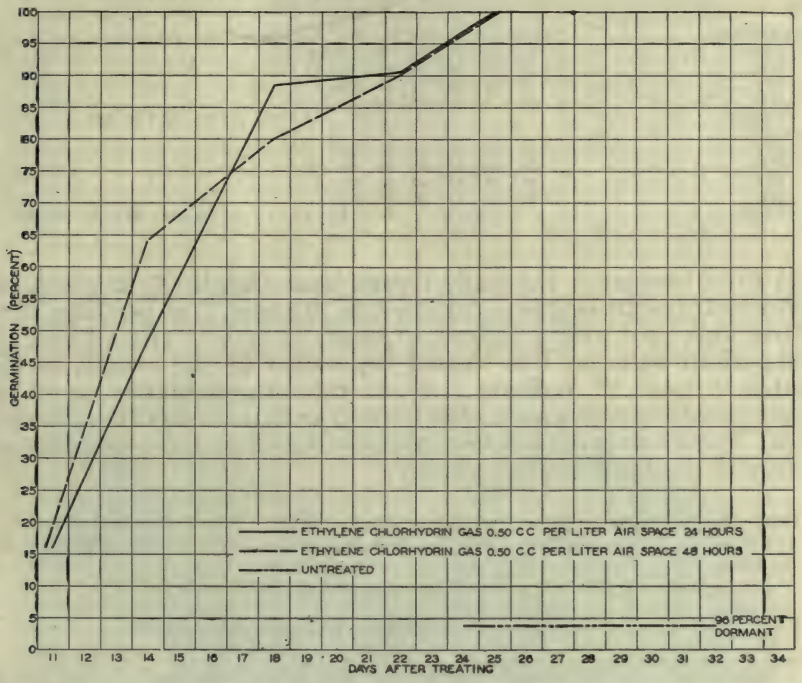
GERMINATION (PERCENT)
DAYS AFTER TREATING
ETHYLENE CHLORHYDRIN GAS 0.50 C C PER LITER AIR SPACE 24 HOURS
ETHYLENE CHLORHYDRIN GAS 0.50 C C PER LITER AIR SPACE 48 HOURS
UNTREATED
96 PERCENT DORMANT

FIGURE 6.—Rate of germination of treated and untreated Triumph tubers harvested September 12 and treated September 28–29, 1931, with ethylene chlorhydrin. Tubers placed in 70° F. room immediately after treatment.

it is found that the resultant averages are remarkably close. For example, the average time interval of both the Irish Cobbler and Triumph in the treatment given September 21 was 25.9 days, with an average germination of 94.5 percent, as compared with 24.6 days and 95-percent germination from the treatment given September 28. During the same period the average germination of the untreated sets was 3.5 and 3.0 percent, respectively. In other words, the data indicate, as might be expected, the natural passage of the rest period. Figures 5 and 6 show, by graphs, the rate of germination of the Irish Cobbler and Triumph treated September 28.

TABLE 12.—*Ethylene chlorhydrin gas treatment with one half cc per liter of air space, using in each test 25 tubers of the Irish Cobbler and Triumph varieties*

[Potatoes harvested Sept. 12 and treated Sept. 28, 1931]

| Variety and condition of whole tubers | Duration of treatment | Rate of germination in— | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 11 days | 14 days | 18 days | 22 days | 25 days | 28 days | 32 days | 35 days | 39 days | 42 days | 46 days | 49 days | 53 days | 56 days | 60 days |
| Irish Cobbler: | *Hours* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Dry | 24 | 8 | 20 | 36 | 48 | 72 | 100 | | | | | | | | | |
| Wet | 24 | 8 | 20 | 48 | 64 | 76 | 84 | 92 | 100 | | | | | | | |
| Dry | 48 | 4 | 32 | 72 | 88 | 100 | | | | | | | | | | |
| Wet | 48 | 8 | 44 | 92 | 92 | 100 | | | | | | | | | | |
| Check | | | | | | | 8 | 12 | 20 | 28 | 56 | 92 | 100 | | | |
| Triumph: | | | | | | | | | | | | | | | | |
| Dry | 24 | 16 | 48 | 88 | 92 | 100 | | | | | | | | | | |
| Wet | 24 | 16 | 44 | 64 | 80 | 88 | 100 | | | | | | | | | |
| Dry | 48 | 16 | 64 | 80 | 92 | 100 | | | | | | | | | | |
| Wet | 48 | 12 | 52 | 76 | 92 | 100 | | | | | | | | | | |
| Check | | | | | | 4 | 4 | 4 | 4 | 8 | 12 | 24 | 48 | 76 | 92 | 96 |

A third treatment was made 1 week later, October 5, in which two concentrations of ethylene chlorhydrin, 0.5 and 1 cc per liter of air space, were used with a uniform exposure of 24 hours for all lots. In comparison with the lots treated September 28 the results, as presented in table 13, indicate a slower rate of germination in all but two treated lots and a somewhat quicker germination of the untreated lots. The lot showing quickest response was from the 1-cc-moistened tubers of the Irish Cobbler variety.

TABLE 13.—*Ethylene chlorhydrin gas treatment with 0.5 and 1 cc per liter of air space for 24 hours, using in each test 20 tubers of the Irish Cobbler and Triumph varieties*

[Potatoes harvested Sept. 12 and treated Oct. 5, 1931]

| Variety and condition of whole tubers | Strength of treatment | Rate of germination in— | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 11 days | 15 days | 18 days | 21 days | 25 days | 28 days | 32 days | 35 days | 39 days | 42 days | 46 days | 49 days | 53 days |
| Irish Cobbler: | *Cc* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Dry | 0.5 | 5 | 20 | 30 | 50 | 80 | 90 | 100 | | | | | | |
| Wet | 1 | 10 | 20 | 30 | 60 | 80 | 90 | 90 | 100 | | | | | |
| Dry | .5 | 10 | 15 | 55 | 65 | 90 | 90 | 100 | | | | | | |
| Wet | 1 | 60 | 70 | 90 | 100 | | | | | | | | | |
| Check | | | | | | | | 10 | 35 | 65 | 80 | 100 | | |
| Triumph: | | | | | | | | | | | | | | |
| Dry | .5 | 25 | 35 | 50 | 65 | 80 | 90 | 90 | 95 | 95 | 100 | | | |
| Wet | 1 | 15 | 50 | 70 | 90 | 90 | 90 | 95 | 95 | 100 | | | | |
| Dry | .5 | 15 | 30 | 60 | 80 | 90 | 95 | 95 | 100 | | | | | |
| Wet | 1 | 25 | 50 | 70 | 85 | 90 | 90 | 90 | 95 | 100 | | | | |
| Check | | | | | | | | 5 | 10 | 35 | 70 | 90 | 90 | 95 |

The fourth set of treatments of the Irish Cobbler and the Triumph also included the Katahdin variety. The treatments differed from those made the week previous in that sacks and baskets were substituted for the wet and dry comparisons.

An examination of the data presented in table 14 would seem to indicate a slight advantage in favor of the basket container in the Triumph and Katahdin, while the response from the Irish Cobbler sacked tubers was slightly though not markedly quicker than those in baskets. It is not felt, however, that the difference was sufficiently marked to be convincing.

TABLE 14.—*Ethylene chlorhydrin gas treatment with 0.5 cc per liter of air space for 24 hours, using in each test 20 tubers of the Irish Cobbler, Triumph, and Katahdin varieties of potatoes*

[The first two varieties were harvested Sept. 12 and the last Oct. 1; treated Oct. 12–13, 1931]

| Variety and container of wet whole tubers | Rate of germination in— | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 days | 13 days | 17 days | 20 days | 24 days | 27 days | 31 days | 33 days | 37 days | 40 days | 44 days |
| Irish Cobbler: | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Sack | | | 5 | 10 | 35 | 95 | 100 | | | | |
| Basket | | 5 | 15 | 25 | 30 | 75 | 100 | | | | |
| Check | | | | | | | 35 | 70 | 85 | 95 | |
| Triumph: | | | | | | | | | | | |
| Sack | 5 | 15 | 45 | 55 | 75 | 90 | 90 | 100 | | | |
| Basket | | 15 | 50 | 75 | 100 | | | | | | |
| Check | | | | | | | | 25 | 55 | 60 | 80 |
| Katahdin: | | | | | | | | | | | |
| Sack | 10 | 15 | 35 | 40 | 40 | 100 | | | | | |
| Basket | 35 | 70 | 85 | 85 | 100 | | | | | | |
| Check | | | | | | 30 | 45 | 55 | 60 | 75 | 100 |

The most outstanding feature of this test is to be noted in the response of the Katahdin tubers to the treatment. Taking into consideration the fact that they were not harvested until October 1 and

FIGURE 7.—Katahdin potatoes: *A*, Treated Oct. 12, 1931, in a 0.5-cc-per-liter concentration of ethylene-chlorhydrin gas for 24 hours: *B*, tuber untreated. Photographed 13 days after treatment.

were treated 11 days afterward it is rather remarkable that the basket-treated lot showed a 35-percent germination in 10 days from time of removal from chamber October 12, 85 percent in 17 days, and 100 percent in 24 days, at which time the untreated or check lot did not show germination. From the standpoint of a short rest period it is equally significant that the untreated Katahdin tubers, although harvested 19 days later than the Irish Cobbler and the Triumph, nevertheless showed a prompter germination (fig. 7).

A fifth treatment of Irish Cobbler and Katahdin potatoes with ethylene-chlorhydrin gas was made October 19 to 21, using concentrations of 0.5 and 1 cc per liter of air space. The 0.5-cc treatment was

continued for 48 hours and the 1-cc treatment for 24 hours. All lots were in burlap sacks. The treated Katahdin tubers gave 100 percent germination with both treatments in 21 days, while the treated Irish Cobbler tubers germinated 100 percent in 25 and 28 days, respectively.

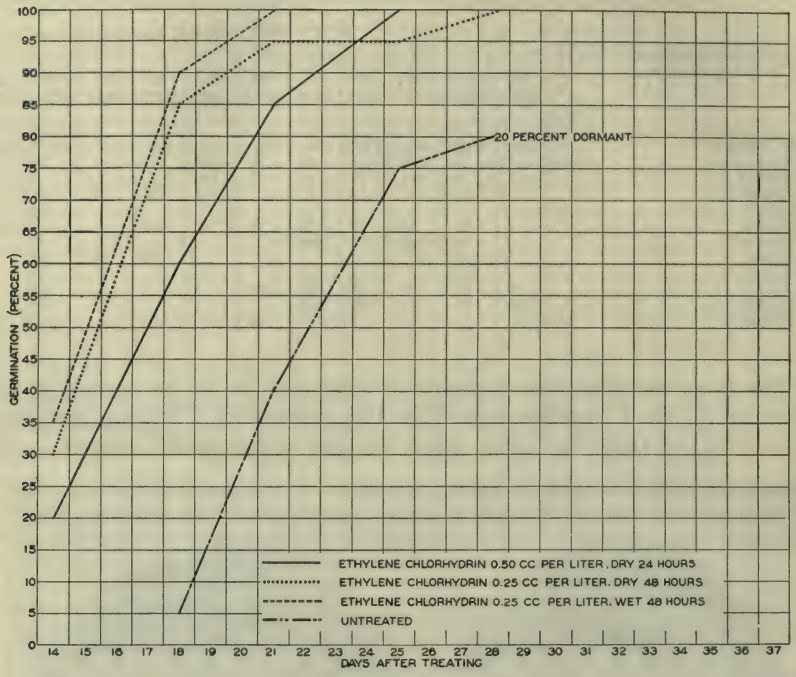
GERMINATION (PERCENT)
DAYS AFTER TREATING
20 PERCENT DORMANT
ETHYLENE CHLORHYDRIN 0.50 CC PER LITER, DRY 24 HOURS
ETHYLENE CHLORHYDRIN 0.25 CC PER LITER, DRY 48 HOURS
ETHYLENE CHLORHYDRIN 0.25 CC PER LITER, WET 48 HOURS
UNTREATED

FIGURE 8.—Rate of germination of treated and untreated Katahdin tubers harvested October 1 and treated October 26–27, 1931, with ethylene chlorhydrin. Tubers placed in a 70° F. room immediately after treatment.

Both lots of untreated tubers gave complete germination in 39 days. Detailed data are presented in table 15.

TABLE 15.—*Ethylene chlorhydrin gas treatment with 0.5 and 1 cc per liter of air space for 24 hours, using in each test 20 tubers of the Irish Cobbler and Katahdin varieties*

[Potatoes harvested Sept. 12 and Oct. 1, respectively; treated Oct. 19–21, 1931]

| Variety and condition of whole tubers | Treatment | | Rate of germination in— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Strength | Period | 11 days | 14 days | 18 days | 21 days | 25 days | 28 days | 32 days | 35 days | 39 days |
| Irish Cobbler: | *Cc* | *Hours* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| Dry, in sacks | 0.5 | 48 | 15 | 40 | 50 | 80 | 95 | 100 | ------ | ------ | ------ |
| Do | 1.0 | 24 | 5 | 45 | 65 | 95 | 100 | ------ | ------ | ------ | ------ |
| Check | ------ | ------ | ------ | ------ | ------ | ------ | 10 | 25 | 70 | 80 | 100 |
| Katahdin: | | | | | | | | | | | |
| Dry, in sacks | .5 | 48 | 30 | 70 | 80 | 100 | ------ | ------ | ------ | ------ | ------ |
| Do | 1.0 | 24 | 25 | 80 | 90 | 100 | ------ | ------ | ------ | ------ | ------ |
| Check | ------ | ------ | ------ | ------ | ------ | ------ | 30 | 50 | 80 | 90 | 100 |

A sixth treatment of Irish Cobbler and Katahdin tubers was made on October 26, 1931, in which the ethylene-chlorhydrin concentrations were at the rate of 0.25 and 0.5 cc per liter of air space. Dry and wet

tubers of each variety were subjected to a 48-hour exposure to the 0.25-cc concentration, while similar lots were given a 24-hour treatment in the 0.5-cc-per-liter concentration. In the case of both the Irish Cobbler and Katahdin there was no material difference in the rate of germination of the dry and wet tubers in the weaker concentration. A slight retardation was noted in the case of the 0.5-percent treatment. The relatively prompt germination of the untreated tubers in both varieties affords conclusive evidence of the passage of the rest period. As usual the Katahdin showed a prompter germination than the Irish Cobbler (table 16 and fig. 8).

TABLE 16.—*Ethylene chlorhydrin gas treatment with 0.25 and 0.5 cc per liter of air space for 24 hours, using in each test 20 tubers of the Irish Cobbler and Katahdin varieties*

[Potatoes harvested Sept. 12 and Oct. 1, and treated Oct. 26, 1931]

| Variety and condition of whole tubers | Treatment | | Rate of germination in— | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Strength | Period | 14 days | 18 days | 21 days | 25 days | 28 days | 32 days |
| Irish Cobbler: | *Cc* | *Hours* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Dry | 0.25 | 48 | 15 | 75 | 90 | 100 | | |
| Wet | .25 | 48 | 25 | 60 | 90 | 95 | 100 | |
| Dry | .5 | 24 | 20 | 32 | 65 | 90 | 100 | |
| Check | | | | | 5 | 50 | 65 | 100 |
| Katahdin: | | | | | | | | |
| Dry | .25 | 48 | 30 | 85 | 95 | 95 | 100 | |
| Wet | .25 | 48 | 35 | 90 | 100 | | | |
| Dry | .5 | 24 | 20 | 60 | 85 | 100 | | |
| Check | | | | 5 | 40 | 75 | 80 | 100 |

A summary of the data for the Irish Cobbler variety, presented in tables 11 to 16, inclusive, shows that the interval between treatment and a 90-percent or even higher germination was 21 days, with an actual average germination of 92.3 percent, as compared with 0.83 percent from the untreated seed.

A similar comparison of the data for the Triumph variety, given in tables 11 to 14, shows a 21¼-day time interval between treatment and an average germination of 94.5 percent, as against no germination from the untreated seed.

The three Katahdin treatments of October 12–13, 19–21, and 26 indicate a 20-day time interval between treatment and a 93.3-percent germination, while the untreated lots gave only 1.67 percent tuber germination.

It should be stated that these data are not based on the average of each period of treatment but on the average of the shortest time intervals in each of the several treatments.

A final treatment of Katahdin potatoes was given November 2 to 4, in which a somewhat extensive comparison was made of the relative efficacy of 0.25- and 0.5-cc concentrations of ethylene chlorhydrin gas treatments for 24 and 48 hours. Both baskets and burlap sacks were used. The promptest germination was obtained from the 0.5-cc treatment, in which tubers in baskets gave 100 percent germination in 18 days. Four lots, two of each concentration, including one of the 24-hour treatment, gave perfect germination in 21 days, while the remaining three lots of treated seed gave complete germination in 25 days. Of greatest interest

is the fact that the untreated lot showed 85 percent germination in the 25-day period (table 17 and fig. 9).

This would seem to indicate that the Katahdin potato has a comparatively short rest period, as only 33 days elapsed between the date of harvesting the seed and its treatment. If to this is added the 25-day interval between treatment and an 85-percent germination of the sets, there is a total of 58 days. It should be

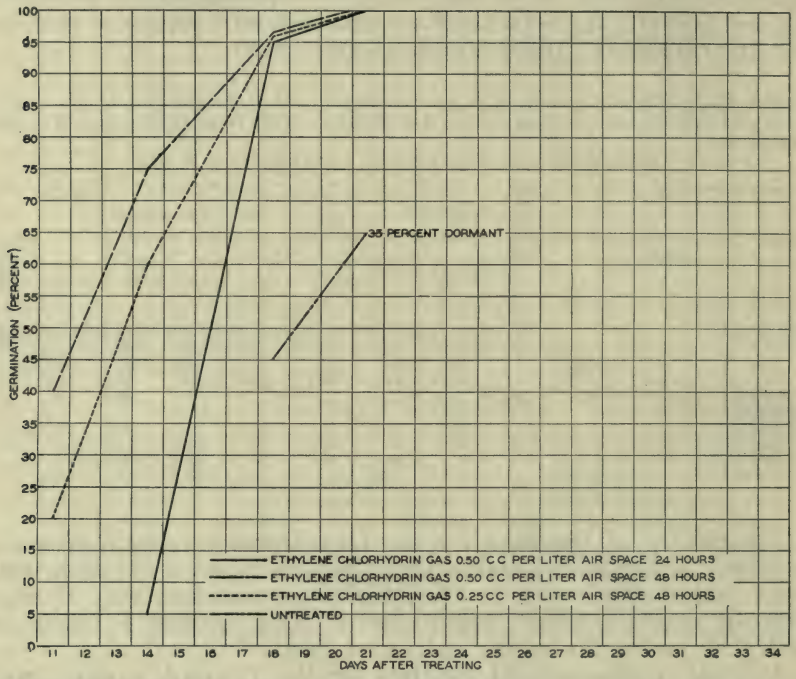
GERMINATION (PERCENT)
DAYS AFTER TREATING
35 PERCENT DORMANT
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 24 HOURS
ETHYLENE CHLORHYDRIN GAS 0.50 CC PER LITER AIR SPACE 48 HOURS
ETHYLENE CHLORHYDRIN GAS 0.25 CC PER LITER AIR SPACE 48 HOURS
UNTREATED

FIGURE 9.—Rate of germination of treated and untreated Katahdin tubers harvested October 1 and treated November 2–3, 1931, with ethylene chlorhydrin. Tubers placed in a 70° F. room immediately after treatment.

stated that the plants when harvested might be regarded as having just reached maturity, so no allowance need be made for their having passed into the rest period before harvesting.

TABLE 17.—*Ethylene-chlorhydrin gas treatment with 0.25- and 0.5-cc per liter of air space for 24 hours, using in each test 20 tubers of the Katahdin variety*

[Potatoes harvested Oct. 1 and treated Nov. 2, 1931]

| Variety and container of dry whole tubers | Treatment | | Rate of germination in— | | | | |
|---|---|---|---|---|---|---|---|
| | Strength | Period | 11 days | 14 days | 18 days | 21 days | 25 days |
| Katahdin: | *Cc* | *Hours* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Sack | 0.25 | 24 | 5 | 25 | 65 | 90 | 100 |
| Basket | .25 | 24 | 5 | 10 | 60 | 90 | 100 |
| Do | .5 | 24 | ------- | 5 | 95 | 100 | ------- |
| Do | .5 | 24 | 5 | 45 | 55 | 95 | 100 |
| Do | .25 | 48 | 20 | 60 | 95 | 100 | ------- |
| Do | .25 | 48 | 10 | 40 | 70 | 100 | ------- |
| Do | .5 | 48 | 40 | 75 | 95 | 100 | ------- |
| Do | .5 | 48 | 30 | 70 | 100 | ------- | ------- |
| Check | ------- | ------- | ------- | ------- | 45 | 65 | 85 |

The question might well be raised in connection with this particular instance as to the value of such late treatments when only a short time interval is gained. This question would also apply in the case of several other varieties herein reported. The writers offer the following reasons: (1) It seemed desirable to study the reaction of the several varieties recorded, in order to ascertain the relative response to certain chemical treatments designed to shorten the rest period. (2) The length of the rest period was deemed worthy of further study; hence, in some instances, as in the case of the Katahdin, it was possible to demonstrate its comparatively short rest period. The writers do not advocate subjecting seed potatoes to chemical treatment for shortening the rest period except when necessary to plant them within a relatively short interval after harvesting. In such cases it is believed that sufficient evidence is now available to assure its successful use commercially.

## SUMMARY AND CONCLUSIONS

The presentation of a paper by Johannsen in 1893 furnished the first evidence of the stimulative effect of anaesthetics on resting plants. It was found that when plants were subjected to ether or chloroform fumes in a tight container for 48 hours or more a marked growth stimulus was produced as an afterresult.

Johannsen's discovery found its greatest immediate application in shortening the rest period of hard-wooded flowering plants.

In recent years other chemical substances have been substituted for ether and chloroform which are equally if not more effective and are more convenient to apply.

Of approximately 224 substances tested for their action in shortening the rest period of potatoes, Denny found that ethylene chlorhydrin and the thiocyanates of sodium and potassium were, on the whole, the most effective.

Chemical treatments of potato sets to shorten the rest period were undertaken during the fall and winter of 1928–29, with the idea of studying its commercial possibilities.

Of the 27 varieties treated, the Prolific showed the quickest response, being closely followed by four others.

The most pronounced results were obtained from sets treated with a 6-percent solution of ethylene chlorhydrin and in 1- and 2-percent solutions of sodium thiocyanate and afterward held in tight containers from 6 to 48 hours.

Plants produced from sets dipped in a 3-percent sodium-thiocyanate solution and held in closed containers for periods of 6, 12, 18, and 24 hours showed considerable foliage injury. This treatment also delayed germination.

A marked difference was noted in the response from sets of Dakota Red treated on November 12, 1928, as compared with that from sets treated December 20, 1928. In the first instance there was no response in 28 days, while in the later treatment 100-percent germination was obtained in 27 days, the difference in response being due to a lessened depth of the rest period.

In the 1929–30 experiment special consideration was given to a study of the relative merits of the ethylene-chlorhydrin and sodium-

thiocyanate treatments. The experiments were conducted with 23 varieties, and, as in the previous seasons, a considerable variation in response was noted. Prolific showed the quickest response from the ethylene-chlorhydrin treatment. Early Rose, Noroton Beauty, Prolific, Burbank, and Keeper appeared to have the shortest rest period.

The most successful results based on relative germination of treated and untreated sets were obtained from White Ohio, Beauty of Hebron, Queen-of-the-Valley, Early Manistee, and the White-Eyed Peachblow.

The 1931 treatments of whole tubers with ethylene-chlorhydrin gas for 24 and 48 hours rather conclusively demonstrated the efficacy of this gas in shortening the rest period.

Sufficient evidence was obtained to justify the statement that certain varieties are more easily stimulated into growth than others. Prolific and Katahdin are apparently sensitive to chemical treatments and also seem to have a short rest period.

The behavior of the untreated potatoes in the summer and fall experiments of 1931 affords a fairly accurate index of the normal rest period of the potato when held at temperatures favorable to germination. It also affords a ready means of studying this factor in seedling progenies.

On the whole, the results obtained during studies covering four seasons indicated a prompter germination response from the ethylene-chlorhydrin treatments than from sodium thiocyanate, but as a rule the latter soon caught up and frequently surpassed the former. This is rather clearly indicated in figures 2 to 9.

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# THE NITROGEN NUTRITION OF TOBACCO

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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Technical Bulletin No. 414 April 1934

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

# THE NITROGEN NUTRITION OF TOBACCO[1]

By W. W. GARNER, *principal physiologist, in charge;* C. W. BACON, *associate physiologist;* J. D. BOWLING, *assistant biochemist;* and D. E. BROWN, *chief scientific aid, Division of Tobacco and Plant Nutrition, Bureau of Plant Industry*

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## INTRODUCTION

It is particularly difficult in the case of tobacco to obtain a satisfactory understanding of the functions and the effects of the essential elements in the nutrition of the plant in relation to practical culture. It is characteristic of the tobacco crop that within reasonable limits the returns realized by the grower usually depend more on the quality of the product than on the yield obtained. In this crop the leaf constitutes the valuable portion and, as is well known, foliage leaves are especially sensitive to changes in the supply of nutrients and other soil and climatic factors with respect to their morphological and histological characteristics and their chemical composition. These physical and chemical characteristics largely determine the commercial value of the tobacco leaf and, moreover, requirements as to these

[1] The investigations here reported were conducted cooperatively by the Bureau of Plant Industry and the Maryland Agricultural Experiment Station.

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properties for the manufacture of cigars, cigarettes, and other tobacco products differ very widely. Finally, the physical and chemical properties of the soil, as well as the climatic conditions required for successful production of leaf tobacco suitable for one manufacturing purpose, may differ radically from those required for obtaining a product adapted to another form of manufacture.

It is known that although nitrogen is one of the essential and characteristic constituents of the living matter of the cell, the quantity absorbed and assimilated by the plant does not bear a fixed relation to the rate or the extent of growth, for this relation is subject to considerable variation in accordance with the supply of nitrogen becoming available in the soil and numerous other factors influencing nutrition and growth. It appears that considerable quantities of assimilated nitrogen may be stored in the tissues in the form of so-called "reserve protein" and related compounds. Available data show that in the tobacco plant the nitrogen content of the mature leaf on a dry basis may range from less than 2 percent to as much as 5 percent or even more, although with the higher percentages appreciable quantities of the nitrogen usually remain in the unassimilated, inorganic form. It is a matter of common observation by growers that variation in the soil supply of nitrogen is likely greatly to affect the value of the cured leaf. Evidence is presented in this bulletin which tends to show that not only does the quantity of nitrogen absorbed and assimilated by the plant affect the grade or quality of the leaf of a given type, but it is also one of the important factors in determining the type of leaf produced; that is, it may largely determine whether the leaf is primarily adapted to manufacture of cigars, cigarettes, or other finished products. In this and in certain other respects nitrogen appears to be of outstanding importance in its effects on the development of the tobacco leaf and on its properties after it has been cured.

Extensive field experimentation in the form of plot tests of the conventional type concerning the nitrogen requirements of the tobacco crop has been carried on in the United States and in foreign lands, but it does not seem necessary for present purposes to review the results obtained. Experiments of this type, when properly planned and carried out, undoubtedly are of great practical value in determining the most profitable usage of nitrogen as a fertilizer for a given type of tobacco under a given set of conditions. From their nature, however, such experiments usually have only a limited more or less local application and cannot be expected to supply adequate information on the more fundamental features of the nitrogen nutrition of the tobacco plant. As far as is known, no comprehensive investigation has been undertaken previously relative to the effects of differences in the quantity of nitrogen made available to the plant upon the physical and chemical properties of the leaf and the internal processes of nutrition and metabolism through which these effects on leaf characteristics are produced.

In addition to the effects of differences in the quantity of nitrogen made available to the plant, there is also the important problem of analyzing the relative effects of inorganic and organic sources or forms of nitrogen on the yield and on the properties of tobacco leaf. There has long been a belief on the part of tobacco growers that organic sources of nitrogen such as cottonseed meal, fish, and slaughterhouse

products are essential as constituents of the fertilizer for production of high quality in certain types of leaf. In this connection it may be noted, however, that in a recent investigation Beaumont and his associates (*5*) [2] found that any special virtue which cottonseed meal may possess as a fertilizer apparently is not based upon any peculiar forms of nitrogen it contains. The comparative effects of organic and inorganic forms of fertilizer nitrogen are not dealt with in this bulletin. Considerable attention is given to the relative effects of ammonia and nitrate forms of nitrogen so far as concerns growth relations, and limited consideration also is given to different ammonia salts, such as the sulphate and the chloride. However, the effects of differences in the quantity rather than in the form of the nitrogen are especially emphasized.

With respect to interpretation of the results of technical nutritional studies relating particularly to nitrogen, such as are included in this bulletin, it is unfortunate that so little is known about the composition and properties of the different proteins and other complex nitrogen compounds functioning in nutrition, metabolism, and growth processes. A principal difficulty is that methods are not available for separating and estimating the specific nitrogen compounds in question. It is hardly possible at present, therefore, to arrive at even an approximately complete analysis of the mode of action of increasing quantities of nitrogen made available to the plant. However, some of the effects on internal processes have been measured, and their apparent relationship to the growth and the properties of the leaf have been established.

## SCOPE AND PLAN OF THE EXPERIMENTS

In the present investigations the two primary objectives were: (1) To obtain practical information about the quantity of fertilizer nitrogen required for best results with respect to yield and market value of the Maryland type of tobacco, also the comparative fertilizing value of some of the new, synthetic forms of nitrogen for the tobacco crop; and (2) to make a fairly comprehensive physiological and biochemical study of the effects of varying the nitrogen supply on the growth and development of the plant, particularly its leaves, and on the associated internal processes of metabolism and nutrition. To attain the first-named objective, field-plot tests of the usual type were conducted for a period of years at Upper Marlboro, Md. The original, more extensive series of plot experiments, was begun in 1919 and was continued for 11 years. Several additional treatments were begun subsequently to 1919. The plots were approximately one twentieth of an acre, with a space of 1½ feet separating them, and every fourth plot was used as a control. The treatments were not duplicated in the usual fashion but instead, at harvest time, each plot was separated transversely into two sections of equal area, and the yields were obtained separately on the duplicate sections. The rows were 34 inches apart, and the plants were spaced 34 inches in the row. All fertilizer was applied in the drill just before transplanting except that beginning in 1925 one half of the nitrogen was applied as a top dressing at the second cultivation on the plots receiving 80 pounds of nitrogen per acre. A Maryland broadleaf variety of tobacco was used, and approved

[2] Italic numbers in parentheses refer to Literature Cited, p. 75.

methods of cultivating, harvesting, and curing, conforming to standard practice in southern Maryland, were used throughout.

All plots in the primary series received a uniform basal fertilizer treatment supplying 60 pounds of phosphoric acid ($P_2O_5$) and 40 pounds of potash per acre. In 1919 the phosphoric acid was supplied in the form of 16 percent superphosphate but thereafter precipitated bone, a dicalcic phosphate containing about 40 percent of phosphoric acid, was substituted. The potash was derived from high-grade sulphate. Evidence of magnesium deficiency having appeared on the plots, ground limestone containing 20 percent of magnesia was applied uniformly at the rate of a ton per acre in the fall of 1922 and of 1924. In 1924, through error, a low-grade muriate of potash containing 38 percent of potash was applied, instead of ammonium sulphate, to the plots regularly receiving the latter form of nitrogen. Consequently, in that year these plots received an excess of potash but no nitrogen at all. Departures from the basal treatment in the supplementary plots later added are considered in connection with the description of quantities and forms of nitrogen employed in the tests.

The principal feature of the physiological and biochemical studies was an attempt to trace through the growing period, the subsequent period of so-called "ripening" of the leaves, and the curing of the harvested product, the effects of varying the amount of the nitrogen supply on various features of growth and development of the plant with special reference to the leaves, and on the internal processes involved. Consideration was given also to effects of the nitrogen supply on the physical and chemical characteristics of the cured leaf in relation to the type, grade, and quality of the product. The physiological observations were concerned mainly with the relative development of leaf, stalk, and root; the rate, amount, and character of growth of leaf and stalk; the time of flowering and the progress of the ripening process; visible symptoms of nitrogen deficiency in the plant; and the combustibility of the cured leaf. In the biochemical studies attention was given to the recovery of fertilizer nitrogen by the plant and its distribution in the plant parts; the minimum nitrogen requirements of the crop; water, osmotic, and acidity relations in the leaf; nitrogen and carbohydrate metabolism; oxidizing enzymes; and the chemical composition of the cured leaf and its significance. Brief consideration also was given to the effects of high and low topping on leaf metabolism. Though the data are far from complete in all particulars, they serve as a whole to throw considerable light on the effect of the nitrogen supply on growth and metabolism, and on the nutrition of the plant and the resultant characteristics of the cured leaf affecting its value for manufacturing purposes.

In technical plant-nutrition studies it is common practice to employ cultures in sand or in nutrient solutions in order to secure better control of conditions, but such methods are not well adapated for work with tobacco which involves detailed study of development and chemical composition of the leaf in relation to quality. In seeking a physiological approach to such tobacco-fertilizer problems as were under investigation, it is believed that, with proper choice of soil type and the other necessary precautions, conditions more or less similar to those applying to sand cultures can be attained in open field cultures. This plan has the important advantage that the results obtained are much more likely to be directly applicable to conditions of commer-

cial culture. In some instances results so obtained may need to be checked by means of pot tests, but in the present case the field plots used in the previously mentioned practical tests and other similar plots supplied substantially all of the material required for the physiological and biochemical observations. Because of the disturbing effects of fluctuating weather conditions and of other variable factors under field conditions, detached observations of a physiological or biochemical nature may not be conclusive, but usually this uncertainty is readily overcome by making a series of observations at intervals, always under strictly comparable conditions and extending over a considerable period. This method also is particularly helpful in guarding against misleading results, due to differences in age or stage of development of different plants or parts of the individual plant.

## CONDITIONS UNDER WHICH EXPERIMENTS WERE CONDUCTED

### QUANTITIES AND FORMS OF NITROGEN USED

Nitrate of soda was employed at rates to supply 10, 20, 30, 40, and 80 pounds of nitrogen per acre. These quantities of nitrogen in combination with the basal supply of phosphoric acid and potash along with the control treatments are equivalent to 1,000 pounds of fertilizer per acre having the formulas 0-6-4, 1-6-4, 2-6-4, 3-6-4, 4-6-4, and 8-6-4, respectively. The outcome of the tests indicates that there would have been some advantage in including in this group a rate of 60 pounds of nitrogen per acre. Further information on the quantity of nitrogen required for best results also was provided in applying the other forms of nitrogen used at two or more different rates.

In the original series, in addition to nitrate of soda, cyanamide and ammonium nitrate were used in quantities to supply 20 and 40 pounds of nitrogen per acre; and ammonium chloride and ammonium sulphate were employed at rates to furnish 20, 40, and 80 pounds of nitrogen per acre.

Beginning in 1921, tests with urea and the commercial product known as Ammo-Phos in comparison with ammonium sulphate, applied at rates to supply 20 and 40 pounds of nitrogen per acre were undertaken on a nearby field having a lighter and somewhat less productive soil. Since the Ammo-Phos contained about 47 percent of phosphoric acid and only 11.5 percent of nitrogen, an additional ammonium-sulphate plot was included which received double the normal application of 60 pounds per acre of phosphoric acid in the form of precipitated bone and the nitrogen was applied at the 40-pound rate. Ground limestone was applied to these plots as in the original series.

In 1923, a test of Urea-Phos, a combination of urea and phosphoric acid, involving plots receiving nitrogen from this source at the rates of 20 and 40 pounds per acre, was added at the front end of the original set of plots. The Urea-Phos contained 45 percent of phosphoric acid and no additional phosphate was used in this experiment.

In 1925 a test of monoammonium phosphate in conjunction with nitrate of potash was added, although the primary object in this instance was to include a highly concentrated fertilizer supplying only the three nutrients, nitrogen, phosphorus, and potassium, rather than to conduct a test with ammonium phosphate as such. The materials were used in proportions to furnish approximately 40 pounds of nitro-

gen, 60 pounds of phosphoric acid, and 90 pounds of potash per acre. For comparison, a treatment was employed in which one half the nitrogen was derived from cottonseed meal and the other half from nitrate of soda; the phosphoric acid from 16 percent superphosphate; and the potash from high-grade sulphate.

The approximate nitrogen content of the materials used in these experiments is shown in table 1.[3]

TABLE 1.—*Approximate content of principal constituents of fertilizer materials used in plot tests*

| Fertilizer material | Composition (percent) | | | Fertilizer material | Composition (percent) | | |
|---|---|---|---|---|---|---|---|
| | Nitrogen | Phosphoric acid ($P_2O_5$) | Potash ($K_2O$) | | Nitrogen | Phosphoric acid ($P_2O_5$) | Potash ($K_2O$) |
| Ammonium nitrate | 34.8 | | | Cyanamide | 20.5 | | |
| Ammonium sulphate | 20.5 | | | Urea | 46.0 | | |
| Ammonium chloride | 25.5 | | | Urea-Phos | 17.7 | 45.0 | |
| Monoammonium phosphate | 11.6 | 62.4 | | Cottonseed meal | 6.0 | 3.0 | 2.0 |
| Sodium nitrate | 15.5 | | | Superphosphate | | 16.0 | |
| Potassium nitrate | 13.7 | | 46.3 | Precipitated bone (dicalcic phosphate) | | 40.0 | |
| Ammo-Phos | 11.5 | 47.0 | | Potassium sulphate | | | 50.0 |

The treatment of the fertilized plots and those used for controls in the original major series of tests are shown in table 5, and in the supplementary series in table 7, and the arrangement of the plots is shown in figure 1.

## SOIL OF THE EXPERIMENTAL PLOTS

In order to obtain as full information as practicable concerning the general characteristics of the soil used in the tests, the Bureau of Chemistry and Soils was requested to make a survey of the plots. This was done, and the results with respect to the original, principal series of plots are indicated in figure 1. The report on the soils of the farm on which the nitrogen plots are located as prepared by S. W. Phillips, Bureau of Chemistry and Soils, has been published in full elsewhere (*9*) in connection with certain other studies made on the farm. As indicated in figure 1, the two soil types found on the principal set of nitrogen plots are the Collington fine sandy loam and the Collington gravelly sandy loam. The supplementary set of plots is composed of the Collington fine sandy loam and Collington loamy sand types.

Prior to the initiation of these experiments the soil had not been cropped for several years. The initial reaction of the soil and subsoil, determined colormetrically, was found to correspond to a pH value of 6.8. Readings on plots 7, 11, 13, 18, 19, and 20 (table 5) were taken in the fall of 1925 and again in 1926 and showed a pH value of about 7.1 for both soil and subsoil on all plots except 19 and 20, which received 80 pounds of nitrogen per acre as chloride and sulphate, respectively, and showed a pH of 6.8.

[3] Most of the nitrogenous materials used and the data on their chemical composition were supplied by the Division of Fertilizer and Fixed Nitrogen Investigations, Bureau of Chemistry and Soils.

### WEATHER CONDITIONS

In interpretation of the results obtained, the amount and distribution of rainfall is of special importance as a factor because of its effect in either increasing or decreasing the available nitrogen in the

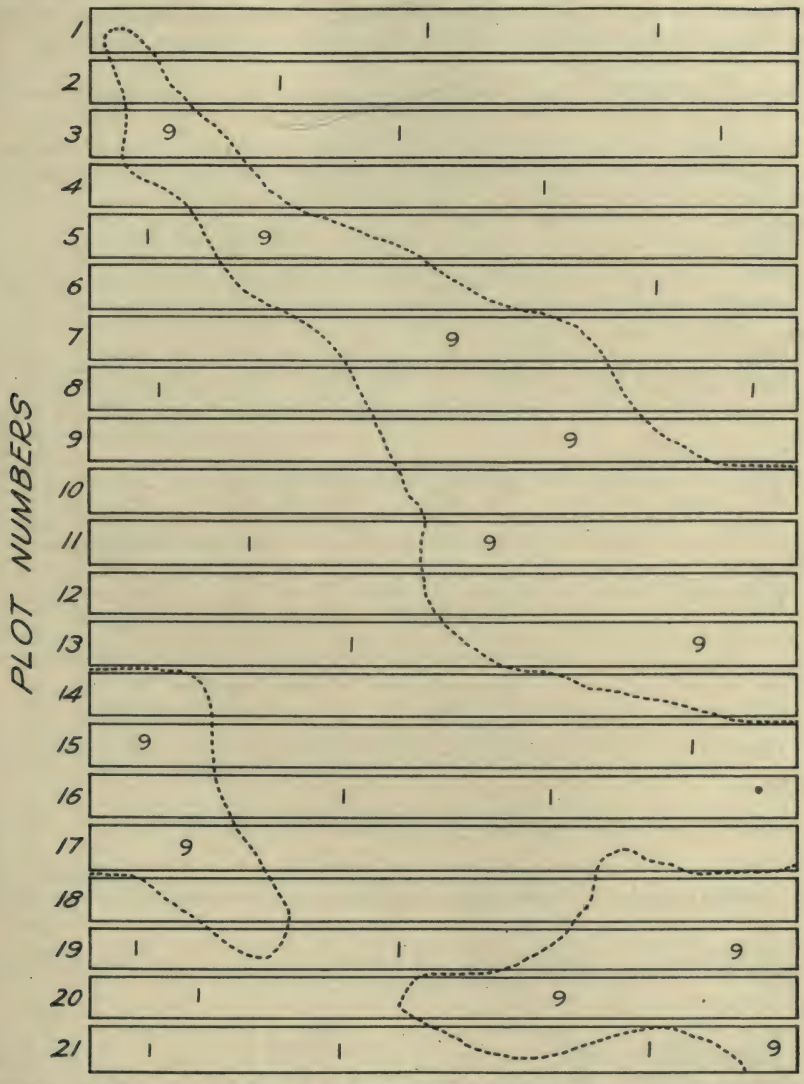


FIGURE 1.—Soil map of principal series of nitrogen test plots, Upper Marlboro, Md. Soil legend: (1) Collington fine sandy loam; (9) Collington gravelly sandy loam. Surveyed November 1921 by S. W. Phillips, Bureau of Chemistry and Soils, United States Department of Agriculture.

soil as well as the direct effect of the water supply on the growth of the plant. It is rather difficult satisfactorily to summarize the complete records of rainfall which were taken during the growing season, but the data for 10-day periods, as shown in table 2, will serve to indicate fairly well for each year the general distribution of the

rainfall through the season. In this connection the dates of transplanting to the field and of harvesting the crop each year are shown in table 3.

The temperature conditions doubtless were not greatly different from those at Washington, D.C., about 15 miles distant, where records reported by the United States Weather Bureau are available to any who may be interested in this feature of the weather conditions.

TABLE 2.—*Rainfall at Upper Marlboro, Md. (in inches), for 10-day periods during the growing season, 1919–29*

| Month and 10-day interval | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| April: | | | | | | | | | | | |
| 1–10 | 2.20 | 2.24 | 0.05 | 0.10 | 0.11 | 2.13 | 0.20 | 1.02 | 1.83 | 0 | 0.70 |
| 11–20 | 1.02 | 1.77 | .66 | .97 | 1.37 | .26 | .66 | .26 | .07 | .93 | 4.15 |
| 21–30 | .69 | .80 | 2.07 | .03 | 1.75 | .08 | .80 | .33 | 4.09 | 3.99 | 2.34 |
| Total | 3.91 | 4.81 | 2.78 | 1.10 | 3.23 | 2.47 | 1.66 | 1.61 | 5.99 | 4.92 | 7.19 |
| May: | | | | | | | | | | | |
| 1–10 | 1.85 | .80 | 1.98 | 1.13 | .90 | 1.49 | .26 | .02 | 1.92 | .29 | 1.19 |
| 11–20 | 3.05 | .08 | 2.33 | 2.81 | .88 | 2.66 | .77 | .82 | .54 | .46 | .39 |
| 21–31 | 1.76 | .18 | .76 | .66 | 0 | 2.10 | 1.13 | .09 | .57 | 1.02 | 2.56 |
| Total | 6.66 | 1.06 | 5.07 | 4.60 | 1.78 | 6.25 | 2.16 | .93 | 3.03 | 1.77 | 4.14 |
| June: | | | | | | | | | | | |
| 1–10 | 1.19 | 2.08 | 0 | 3.60 | .93 | 2.71 | 0 | 1.04 | 0 | .42 | .66 |
| 11–20 | .23 | 2.40 | .31 | 1.86 | 1.58 | 1.11 | .04 | .52 | 3.25 | 1.13 | 3.02 |
| 21–30 | .87 | 1.24 | .46 | 2.80 | .48 | 1.38 | 1.73 | .89 | .34 | 2.28 | 2.61 |
| Total | 2.29 | 5.72 | .77 | 8.26 | 2.99 | 5.20 | 1.77 | 2.45 | 3.59 | 3.83 | 6.29 |
| July: | | | | | | | | | | | |
| 1–10 | 1.63 | 2.35 | 1.31 | 2.36 | .97 | 1.08 | 2.83 | 1.56 | .48 | .07 | 1.99 |
| 11–20 | 2.58 | 1.73 | 1.46 | 3.65 | 1.62 | .03 | .32 | 2.56 | .60 | 2.35 | .74 |
| 21–31 | 2.43 | .55 | .37 | .73 | 1.13 | .68 | 3.55 | .65 | .33 | 0 | .14 |
| Total | 6.64 | 4.63 | 3.14 | 6.74 | 3.72 | 1.79 | 6.70 | 4.77 | 1.41 | 2.42 | 2.87 |
| August: | | | | | | | | | | | |
| 1–10 | .83 | .66 | .73 | .41 | .70 | .86 | 1.12 | .54 | .07 | .89 | .90 |
| 11–20 | 3.07 | 1.49 | 1.45 | 2.73 | 1.71 | 2.15 | .85 | 3.70 | 2.43 | 11.72 | 0 |
| 21–31 | .40 | 2.15 | .10 | .68 | .45 | 1.72 | .65 | 2.37 | 3.06 | 1.15 | .45 |
| Total | 4.30 | 4.30 | 2.28 | 3.82 | 2.86 | 4.73 | 2.62 | 6.61 | 5.56 | 13.76 | 1.35 |
| September: | | | | | | | | | | | |
| 1–10 | .19 | 1.24 | .36 | .63 | 1.52 | .54 | .62 | 2.48 | 1.85 | 2.10 | 1.33 |
| 11–20 | .77 | .03 | .02 | 0 | .39 | .79 | .92 | 0 | .44 | 1.47 | 1.28 |
| 21–30 | .73 | 2.05 | 1.41 | 0 | .62 | 4.26 | .23 | 1.61 | 0 | .74 | 1.10 |
| Total | 1.69 | 3.32 | 1.79 | .63 | 2.53 | 5.59 | 1.77 | 4.09 | 2.29 | 4.31 | 3.71 |
| Total for 6 months | 25.49 | 23.84 | 15.83 | 25.15 | 17.11 | 26.03 | 16.68 | 20.46 | 21.87 | 31.01 | 25.55 |

TABLE 3.—*Dates of transplanting and harvesting the tobacco of the experimental plots each year, 1919–29*

| Year | Date of transplanting | Date of harvesting | Year | Date of transplanting | Date of harvesting | Year | Date of transplanting | Date of harvesting |
|---|---|---|---|---|---|---|---|---|
| 1919 | June 26 | Oct. 10 | 1923 | June 27 | Sept. 28 | 1927 | June 15 | Sept. 9 |
| 1920 | June 25 | Sept. 17 | 1924 | June 26 | Oct. 10 | 1928 | June 19 | Sept. 14 |
| 1921 | July 1 | Oct. 5 | 1925 | June 19 | Sept. 4 | 1929 | June 28 | Oct. 8 |
| 1922 | June 14 | Sept. 22 | 1926 | June 15 | Sept. 17 | | | |

## EFFECTS OF SUPPLY OF FERTILIZER NITROGEN ON CROP YIELDS

In the primary or major series of plot tests the average yields of cured leaf on the duplicate sections of the control plots (table 4) indicate only a fair degree of uniformity in the productivity of the soil as a whole, the yields of sections A and B of plot 1 and section A of plots 5 and 17 pointing to a somewhat greater natural productivity of the adjoining soil than that of the remainder of the field. When plot 1 is excluded the average yield of the remaining controls is 614 pounds, while including this plot gives an average yield of 634 pounds. It is recognized that there are differences of opinion as to the most satisfactory manner of applying the results from control plots in interpreting experimental data, but in the present instance the results on plot 1 will be excluded, and the average value of 614 pounds for the remaining controls applied uniformly in all cases in arriving at the effects of the nitrogen treatments.

In the supplementary series of plots the average yields of the three controls (table 7) are 464, 534, and 524 pounds, respectively. The general average for the three controls is 507 pounds. It appears, therefore, that the soil of this field is somewhat less productive than that of the primary series of tests.

TABLE 4.—*Average yields per acre of duplicate sections of control plots in the primary series of nitrogen tests, 1919–29*

| Plot section | Plot 1 | Plot 5 | Plot 9 | Plot 13 | Plot 17 | Plot 21 |
|---|---|---|---|---|---|---|
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| A | 771 | 682 | 545 | 581 | 670 | 593 |
| B | 692 | 601 | 607 | 630 | 607 | 614 |
| Average | 732 | 642 | 576 | 606 | 639 | 604 |

The effectiveness of nitrogen as a fertilizer in promoting growth on the several plots in both the early and later stages of development of the plants is indicated in figures 2 and 3.

### EFFECTS OF INCREASING QUANTITIES OF NITROGEN

The average annual yields of the duplicate plot sections in leaf and stalk, the 10-year average yield of leaf on each of the duplicate sections of each plot, and the 10-year combined average yield of leaf and of stalk on the two sections of each plot in the primary series are shown in table 5. This table also indicates the arrangement of the plots. The yearly yields on the duplicate sections of each plot were reasonably consistent and are not given in detail in the table. The average increase in yield over the controls for each treatment covering the entire period of the experiment, except the year 1924, is shown in table 6.

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FIGURE 2.—Primary series of plots, season of 1920, showing the effectiveness of fertilizer nitrogen in the early stages of growth. The plot in the center received no nitrogen, while the plants at left received 20 pounds per acre in the form of ammonium chloride, and those at right received a like quantity in the form of ammonium sulphate.

FIGURE 3.—Supplementary series of plots, season of 1926, showing the effectiveness of nitrogen as a fertilizer in the late stages of growth. Plot at right of measuring rod received no nitrogen, while plot at left received 40 pounds of nitrogen per acre in the form of ammonium sulphate. The plants receiving no nitrogen in the fertilizer show a pale yellowish-green color, a characteristic symptom of nitrogen hunger.

TABLE 5.—*Yields of leaf and stalk each year, 1919–29 (average of duplicate sections, A and B, of each plot), 10-year average yield of leaf on each of the two plot sections, and the 10-year combined average yield of leaf and of stalk on the two sections of each plot, in the primary series of tests with nitrogen applied at different rates and derived from different sources, 1919–29*

[Results for 1924 are not included in the 10-year averages for reasons stated on page 4]

| Plot no. | Nitrogen applied | | Acre yields of leaf and stalk (pounds) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity per acre | Source | 1919 | | 1920 | | 1921 | | 1922 | | 1923 | | 1924 | | 1925 | |
| | | | Leaf | Stalk | Leaf | Stalk | Leaf | Stalk | Leaf | Stalk | Leaf | Stalk | Leaf | Stalk | Leaf | Stalk |
| | *Lb.* | | | | | | | | | | | | | | | |
| 1 | 0 | | 674 | 435 | 600 | 325 | 630 | 290 | 518 | 170 | 785 | 735 | 675 | 225 | 800 | 460 |
| 2 | 20 | Cyanamide | 838 | 690 | 760 | 555 | 700 | 335 | 543 | 230 | 930 | 805 | 1,063 | 555 | 965 | 610 |
| 3 | 20 | Ammonium nitrate | 828 | 705 | 815 | 660 | 785 | 435 | 610 | 285 | 965 | 865 | 713 | 290 | 1,035 | 700 |
| 4 | 20 | Ammonium sulphate | 818 | 685 | 945 | 715 | 670 | 380 | 665 | 345 | 840 | 725 | 783 | 415 | 1,045 | 685 |
| 5 | 0 | | 552 | 360 | 450 | 240 | 580 | 250 | 370 | 135 | 775 | 590 | 603 | 225 | 740 | 340 |
| 6 | 20 | Ammonium chloride | 930 | 740 | 950 | 700 | 666 | 300 | 740 | 335 | 930 | 720 | 990 | 555 | 1,055 | 625 |
| 7 | 20 | Nitrate of soda | 695 | 630 | 800 | 540 | 770 | 420 | 675 | 300 | 940 | 720 | 873 | 485 | 1,125 | 740 |
| 8 | 10 | do | 690 | 510 | 740 | 390 | 600 | 305 | 503 | 175 | 918 | 650 | 740 | 320 | 870 | 520 |
| 9 | 0 | | 523 | 375 | 450 | 230 | 555 | 290 | 325 | 65 | 715 | 510 | 483 | 145 | 745 | 375 |
| 10 | 30 | Nitrate of soda | 843 | 695 | 950 | 660 | 870 | 445 | 520 | 215 | 1,170 | 820 | 880 | 560 | 1,140 | 755 |
| 11 | 40 | do | 790 | 705 | 970 | 670 | 845 | 430 | 580 | 255 | 1,165 | 840 | 895 | 590 | 1,225 | 790 |
| 12 | 40 | Ammonium sulphate | 877 | 880 | 1,045 | 830 | 735 | 350 | 700 | 355 | 1,008 | 765 | 530 | 165 | 1,085 | 790 |
| 13 | 0 | | 579 | 410 | 380 | 195 | 520 | 260 | 335 | 80 | 748 | 520 | 565 | 165 | 755 | 440 |
| 14 | 40 | Ammonium chloride | 1,104 | 910 | 1,195 | 900 | 815 | 350 | 785 | 300 | 1,070 | 695 | 1,093 | 635 | 1,160 | 710 |
| 15 | 40 | Ammonium nitrate | 1,008 | 825 | 1,175 | 885 | 950 | 545 | 735 | 350 | 1,310 | 985 | 1,090 | 740 | 1,190 | 910 |
| 16 | 40 | Cyanamide | 879 | 650 | 960 | 610 | 555 | 260 | 643 | 225 | 805 | 515 | 850 | 370 | 1,070 | 690 |
| 17 | 0 | | 598 | 365 | 500 | 235 | 715 | 360 | 315 | 70 | 795 | 600 | 525 | 185 | 835 | 460 |
| 18 | 80 | Nitrate of soda | 868 | 675 | 1,015 | 735 | 965 | 475 | 413 | 125 | 1,285 | 890 | 1,115 | 750 | 1,260 | 890 |
| 19 | 80 | Ammonium sulphate | 1,133 | 895 | 1,235 | 775 | 705 | 420 | 408 | 160 | 1,120 | 760 | 415 | 140 | 1,230 | 880 |
| 20 | 80 | Ammonium chloride | 1,295 | 975 | 1,210 | 850 | 525 | 205 | 490 | 145 | 845 | 475 | 900 | 445 | 1,200 | 790 |
| 21 | 0 | | 602 | 420 | 580 | 260 | 640 | 325 | 350 | 85 | 600 | 460 | 340 | 85 | 780 | 480 |
| | Average | | 815 | 645 | 844 | 569 | 704 | 354 | 534 | 210 | 940 | 697 | 767 | 383 | 1,015 | 649 |

| Plot no. | Nitrogen applied | | Acre yields of leaf and stalk (pounds) | | | | | | | | | | 10-year average, sections A and B | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity per acre | Source | 1926 | | 1927 | | 1928 | | 1929 | | 10-year average, section A—leaf | 10-year average, section B—leaf | | |
| | | | Leaf | Stalk | Leaf | Stalk | Leaf | Stalk | Leaf | Stalk | | | Leaf | Stalk |
| | *Lb.* | | | | | | | | | | | | | |
| 1 | 0 | | 935 | 655 | 965 | 480 | 395 | 225 | 1,015 | 500 | 771 | 692 | 732 | 428 |
| 2 | 20 | Cyanamide | 935 | 840 | 1,150 | 720 | 510 | 350 | 1,125 | 505 | 866 | 827 | 847 | 564 |
| 3 | 20 | Ammonium nitrate | 960 | 890 | 1,245 | 780 | 580 | 490 | 1,145 | 610 | 949 | 844 | 897 | 642 |
| 4 | 20 | Ammonium sulphate | 885 | 775 | 1,140 | 700 | 565 | 485 | 1,115 | 670 | 882 | 855 | 869 | 617 |
| 5 | 0 | | 835 | 535 | 935 | 380 | 320 | 200 | 860 | 410 | 682 | 601 | 642 | 349 |
| 6 | 20 | Ammonium chloride | 985 | 790 | 1,315 | 800 | 615 | 440 | 1,145 | 645 | 979 | 884 | 932 | 610 |
| 7 | 20 | Nitrate of soda | 805 | 780 | 1,050 | 710 | 550 | 480 | 1,320 | 710 | 868 | 878 | 872 | 603 |
| 8 | 10 | do | 770 | 620 | 905 | 465 | 455 | 330 | 995 | 525 | 746 | 743 | 745 | 449 |
| 9 | 0 | | 635 | 450 | 730 | 265 | 290 | 165 | 790 | 305 | 545 | 607 | 576 | 303 |
| 10 | 30 | Nitrate of soda | 905 | 810 | 1,240 | 745 | 540 | 455 | 1,320 | 705 | 903 | 997 | 950 | 631 |
| 11 | 40 | do | 1,005 | 860 | 1,355 | 855 | 545 | 550 | 1,240 | 740 | 937 | 1,007 | 972 | 670 |
| 12 | 40 | Ammonium sulphate | 1,010 | 920 | 1,335 | 1,000 | 600 | 630 | 1,225 | 710 | 963 | 961 | 962 | 723 |
| 13 | 0 | | 890 | 615 | 760 | 310 | 290 | 180 | 800 | 330 | 581 | 630 | 606 | 334 |
| 14 | 40 | Ammonium chloride | 1,010 | 705 | 1,325 | 945 | 610 | 570 | 1,225 | 660 | 1,036 | 1,024 | 1,030 | 675 |
| 15 | 40 | Ammonium nitrate | 1,035 | 930 | 1,175 | 790 | 655 | 565 | 1,250 | 780 | 1,070 | 1,009 | 1,040 | 757 |
| 16 | 40 | Cyanamide | 1,090 | 785 | 1,090 | 565 | 395 | 245 | 1,035 | 470 | 865 | 836 | 851 | 511 |
| 17 | 0 | | 850 | 460 | 705 | 255 | 285 | 170 | 785 | 280 | 670 | 607 | 640 | 326 |
| 18 | 80 | Nitrate of soda | 1,205 | 865 | 1,525 | 1,110 | 615 | 415 | 1,490 | 800 | 1,094 | 1,034 | 1,064 | 698 |
| 19 | 80 | Ammonium sulphate | 1,345 | 970 | 1,370 | 1,050 | 830 | 755 | 1,220 | 685 | 1,056 | 1,057 | 1,057 | 735 |
| 20 | 80 | Ammonium chloride | 1,370 | 850 | 1,605 | 975 | 785 | 630 | 1,340 | 635 | 1,100 | 1,033 | 1,067 | 653 |
| 21 | 0 | | 760 | 405 | 655 | 270 | 260 | 155 | 780 | 295 | 593 | 614 | 604 | 316 |
| | Average | | 963 | 739 | 1,122 | 679 | 505 | 404 | 1,106 | 570 | 865 | 845 | 855 | 552 |

TABLE 6.—*Increase in yield of tobacco resulting from use of nitrogen in different quantities and from different sources in the primary series (1919–23 and 1925–29) and the supplementary series (1921–23 and 1925–29) of field-plot tests*

[The last plot in the supplementary series received a double ration of phosphoric acid]

| Series of test and source of nitrogen | Acre increase in yield from indicated quantities of nitrogen | | | | |
|---|---|---|---|---|---|
| | 10 pounds | 20 pounds | 30 pounds | 40 pounds | 80 pounds |
| Primary series: | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Nitrate of soda | 131 | 258 | 336 | 358 | 450 |
| Ammonium nitrate | ---------- | 283 | ---------- | 426 | ---------- |
| Ammonium chloride | ---------- | 318 | ---------- | 416 | 453 |
| Ammonium sulphate | ---------- | 255 | ---------- | 348 | 443 |
| Cyanamide | ---------- | 233 | ---------- | 237 | ---------- |
| Supplementary series: | | | | | |
| Urea | ---------- | 299 | ---------- | 491 | ---------- |
| Ammo-Phos | ---------- | 235 | ---------- | 381 | ---------- |
| Ammonium sulphate | ---------- | 254 | ---------- | 423 | ---------- |
| Do | ---------- | ---------- | ---------- | 465 | ---------- |

The nitrate of soda tests of the primary series show increases in yield for each increment of nitrogen but, as is to be expected, the

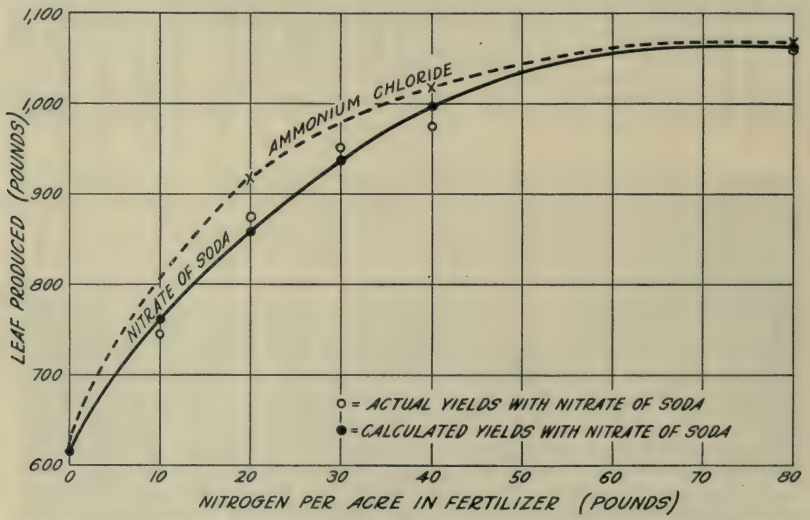


FIGURE 4.—Second-degree parabola, showing the theoretical 10-year average yields of leaf tobacco with 10-pound increments of fertilizer nitrogen derived from nitrate of soda, as compared with the actual average yields; also, comparative actual yields of leaf from equal quantities of fertilizer nitrogen derived from nitrate of soda and ammonium chloride. Note the stimulating action of the chloride ion on leaf yield.

rates of gain for the higher rates of fertilization are less than those for the lower rates (fig. 4). However, there is uncertainty as to what extent the result obtained with 80 pounds of nitrogen as compared with the lower rates is to be attributed merely to the quantity of nitrogen used. In the first 5 years of the test all the nitrogen in the 80-pound rate was applied prior to transplanting, as was done with the lower rates of fertilizing. Under these conditions the concentration of the soil solution seemed to be excessive, the plants were retarded in growth in the early stages, and the final yield from the 80-pound rate averaged only slightly better than that from the 40-

pound rate. In 1925, and thereafter, one half of the nitrogen of the 80-pound rate was applied about 30 days after transplanting. This plan of splitting the nitrogen application prevented the early retarding action on growth of the plants and materially increased the yield. For the period in which all of the nitrogen was applied prior to transplanting, the average increase from the 80-pound rate of fertilizing above the 40-pound rate was only 39 pounds or 4.5 percent, while splitting the 80-pound ration of nitrogen in later years gave an increase of 145 pounds or 14 percent. It appears, therefore, that the method of application became a factor of importance when the rate of nitrogen fertilization was increased to 80 pounds per acre. Nothing can be said as to whether fractionation of the applications in the lower rates of nitrogen fertilization would have materially affected the results.

Under the conditions of the experiment, with an average yield of 614 pounds of leaf on the control plots, for the entire 10-year period the net increases in yield per acre for each successive 10-pound increment of nitrogen in the fertilizer in the nitrate of soda series were 131, 127, 78, and 22 pounds, respectively, for the 10-, 20-, 30-, and 40-pound rates of fertilizing. The 80-pound rate of fertilization gave an average increase in yield over the 40-pound rate amounting to 92 pounds per acre. Additional information on the effects of increasing the nitrogen supply on yield of leaf is furnished by the combined average results for the 10-year period obtained with nitrate of soda, ammonium chloride, and ammonium sulphate at the rates used, namely, those supplying 20, 40, and 80 pounds of nitrogen per acre. The first 20-pound increment of nitrogen gave an increase in yield of 277 pounds of leaf and the second 20-pound increment produced a further increase of 97 pounds, as compared with 258 pounds and 100 pounds, respectively, obtained with the nitrate of soda alone. The 80-pound rate of fertilization gave an increase over the 40-pound rate amounting to 75 pounds per acre.

The results of the supplementary tests (table 7) are not strictly comparable with those of the primary series, the average yield of the controls for the period of the test of the former being 507 pounds against 631 pounds for the controls of the latter series for the same period. On this soil the increase in yield of leaf tobacco for the first 20 pounds of nitrogen applied as ammonium sulphate was 254 pounds and the second 20 pounds gave a further increase of 169 pounds. Thus, on the poorer soil the fertilizer nitrogen at the higher rate has been somewhat more effective in promoting growth of the crop although the actual yields have been lower than those of the primary series. The urea and the Ammo-Phos show about the same relative efficiency at the two rates of application as does the ammonium sulphate.

TABLE 7.—*Average acre yield and value and average price per pound of tobacco on duplicate plot sections in the supplementary tests with nitrogen applied at different rates and derived from different sources, 1921–29*

[Plot 30 received an additional application of 80 pounds of phosphoric acid per acre. Results for 1924 are not included in the 8-year averages]

| Plot no. | Nitrogen applied | | Yield | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity per acre | Source | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 8-year average |
| | *Pounds* | | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| 22 | 0 | | 525 | 162 | 520 | 535 | 600 | 505 | 550 | 175 | 675 | 464 |
| 23 | 20 | Urea | 855 | 365 | 775 | 855 | 1,025 | 915 | 1,110 | 440 | 960 | 806 |
| 24 | 20 | Ammonium sulphate | 790 | 350 | 795 | 477 | 855 | 875 | 1,000 | 460 | 965 | 761 |
| 25 | 20 | Ammo-Phos | 570 | 432 | 660 | 895 | 875 | 935 | 975 | 480 | 1,010 | 742 |
| 26 | 0 | | 505 | 245 | 615 | 567 | 725 | 690 | 505 | 250 | 740 | 534 |
| 27 | 40 | Urea | 775 | 730 | 980 | 1,227 | 1,145 | 1,190 | 1,230 | 540 | 1,395 | 998 |
| 28 | 40 | Ammonium sulphate | 760 | 522 | 820 | 582 | 1,120 | 1,095 | 1,265 | 540 | 1,320 | 930 |
| 29 | 40 | Ammo-Phos | 470 | 457 | 865 | 1,155 | 1,040 | 1,080 | 1,300 | 610 | 1,265 | 886 |
| 30 | 40 | Ammonium sulphate | 850 | 622 | 975 | 562 | 1,130 | 1,090 | 1,210 | 640 | 1,255 | 972 |
| 31 | 0 | | 380 | 217 | 575 | 692 | 725 | 835 | 560 | 245 | 655 | 524 |
| | Average | | 648 | 410 | 758 | 755 | 924 | 921 | 971 | 438 | 1,024 | 762 |

| Plot no. | Nitrogen applied | | Value | | | | | | | | | | 8-year average price per pound |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity per acre | Source | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 8-year average | |
| | *Pounds* | | *Dol.* | *Dol.* | *Dol.* | *Dol.* | *Dol.* | *Dol.* | *Dol.* | *Dol.* | *Dol.* | *Dol.* | *Cents* |
| 22 | 0 | | 96 | 17 | 87 | 70 | 65 | 65 | 34 | 16 | 38 | 52 | 11 |
| 23 | 20 | Urea | 201 | 75 | 154 | 138 | 163 | 194 | 220 | 91 | 174 | 159 | 20 |
| 24 | 20 | Ammonium sulphate | 203 | 65 | 216 | 79 | 171 | 178 | 180 | 94 | 158 | 158 | 21 |
| 25 | 20 | Ammo-Phos | 130 | 75 | 150 | 149 | 172 | 187 | 165 | 100 | 171 | 144 | 19 |
| 26 | 0 | | 94 | 37 | 113 | 66 | 80 | 97 | 38 | 36 | 87 | 73 | 14 |
| 27 | 40 | Urea | 197 | 157 | 295 | 249 | 265 | 234 | 246 | 126 | 184 | 213 | 21 |
| 28 | 40 | Ammonium sulphate | 168 | 99 | 214 | 66 | 246 | 240 | 260 | 109 | 229 | 196 | 21 |
| 29 | 40 | Ammo-Phos | 107 | 79 | 250 | 183 | 257 | 215 | 267 | 134 | 207 | 190 | 21 |
| 30 | 40 | Ammonium sulphate | 198 | 101 | 278 | 60 | 291 | 237 | 260 | 143 | 219 | 216 | 22 |
| 31 | 0 | | 65 | 18 | 114 | 88 | 68 | 98 | 30 | 31 | 72 | 62 | 12 |
| | Average | | 146 | 72 | 187 | 115 | 178 | 175 | 170 | 88 | 154 | 146 | |

Tables 5 and 7 show clearly that weather conditions have profoundly affected the results. Taking the annual averages of all treatments as an index, in the primary series the yield in 1922 and 1928 was only about 500 pounds, while in 1927 and 1929 the yield was about 1,100 pounds. In the supplementary series the corresponding yields were approximately 400 and 1,000 pounds. These wide variations in yield from year to year apply to the controls and to all treatments. However, the widest fluctuations in yield are seen in the heaviest rates of fertilizing. It is interesting to note, also, that the changes in yield in the control plots from year to year are not always in the same direction as the changes in yield in the plots receiving nitrogen. For the most part, however, the same general direction of change in yield is seen in the plots receiving different quantities of nitrogen. Considering both the bad and the good years, it appears that 20 pounds of nitrogen per acre has given more consistent and relatively larger increases in yield than the 40-

and 80-pound rates of fertilizing. The generally poor results of 1928 were due to the extraordinarily heavy rainfall in August, and the very low yields of 1922 probably were caused also by the heavy rainfall of June and July. Taking the results as a whole, nitrogen was especially effective as a fertilizer in 1920, 1925, 1927, and 1929. While there is no close correlation with rainfall, it appears that the good results obtained in these years are associated with a moderate to a fairly liberal rainfall during June, July, and August. The results were less satisfactory in the relatively dry season of 1921. In 1926, the only year in which the first 20 pounds of fertilizer nitrogen was markedly ineffective, the rainfall for July and August was rather heavy.

The duration of the tests was too short, of course, to develop definite trends in the results which would be independent of seasonal effects. However, it is evident that there has been no sustained or progressive decline in yield through the period of the tests even on the control plots which received no nitrogen during the 11 years of the experiment. It seems that a low balance in the nitrogen supply of the soil is established and maintained through additions from outside sources, such as fixation of nitrogen by micro-organisms of the soil.

### EFFECTS OF FORM OF NITROGEN APPLIED

The data in table 6 show the comparative effects of the different forms of nitrogen used in the experiments on the average yield of tobacco over a period of 10 years for the primary series and 8 years for the supplementary series. All forms of nitrogen tested were used at the rates of 20 and 40 pounds per acre and 3 forms also were tested at the rate of 80 pounds per acre. At the 20-pound rate, ammonium chloride stands out as producing the highest yield in the primary series and ammonium nitrate ranks second, while at the 40-pound rate these 2 forms of nitrogen jointly head the list, with no material difference between them. In these tests nitrate of soda and ammonium sulphate gave somewhat lower yields, and at both the 20- and 40-pound rates these 2 sources of nitrogen produced results agreeing rather closely. At the 80-pound rate of application ammonium chloride, ammonium sulphate, and nitrate of soda gave practically identical results.

When used to supply 20 pounds of nitrogen per acre cyanamide gave fairly satisfactory results, the yield falling somewhat below that of nitrate of soda or ammonium sulphate. At the 40-pound rate the results with cyanamide were unsatisfactory. The yield was the same as with the 20-pound rate and the lower leaves of the plant developed a characteristic spotting although in some years the leaves eventually recovered from these toxic effects. The spots produced on the leaves of tobacco by cyanamide resemble somewhat those caused by magnesium deficiency but do not so definitely originate at the tip or margin of the leaf.

In the supplementary series of tests urea gave appreciably better yields than ammonium sulphate at both the 20- and 40-pound rates of fertilization. Ammo-Phos fell somewhat below the ammonium sulphate in efficiency at the two rates of application because of poor results prior to application of magnesian limestone to the soil. The yield from ammonium sulphate was increased slightly by an increased supply of precipitated dicalcic phosphate. In the plot tests with a

urea phosphate which were added to the primary series in 1923 the average increase in yield for the 8-year period with 20 pounds of nitrogen per acre from this source was 187 pounds and with 40 pounds of nitrogen per acre the increase in yield was 407 pounds. The average yield of the control (control plot 1) for the same period was 817 pounds. As previously pointed out (p. 9), the yield on plot 1 has materially exceeded that of the remaining controls, indicating that the soil of the urea-phosphate plot was somewhat more productive than that of the other plots in the series. The indications are that urea phosphate will compare favorably with the other sources of nitrogen used in the experiments.

The relative efficiency of the different sources of nitrogen varied somewhat from year to year. On a comparative basis, nitrate of soda gave poorest results in 1919 and 1926 and best results in 1925; ammonium sulphate ranked low in 1921 and high in 1920; ammonium nitrate was not notably low in efficiency in any year but was particularly effective in 1921 and 1923; ammonium chloride made its poorest showing in 1921 and its best showing in 1919 and 1927. These results, however, do not seem to be closely correlated with differences in rainfall. In the supplementary series there were no striking variations from year to year in relative efficiency of urea, Ammo-Phos and ammonium sulphate.

### RESULTS WITH MONOAMMONIUM PHOSPHATE AND NITRATE OF POTASH

In a series of tests with monoammonium phosphate and nitrate of potash the treatments were run in duplicate, and, as in the other tests, each plot was divided at harvest time into two equal sections, *A* and *B*. The tests have been made each year beginning with 1925, but the crop was so badly damaged by a severe rain and wind storm in August 1928 that reliable yield data could not be obtained for that year. The control plots received no fertilizer at all. The detailed results for the years 1925–27, and 1929 are shown in table 8.

TABLE 8.—*Average yield of tobacco on duplicate sections, A and B, of plots run in duplicate in the years 1925–27 and 1929, showing the rapid decline in yield obtained with a fertilizer composed of ammonium phosphate and nitrate of potash as a result of rapid depletion of the soil supply of calcium and magnesium*

| Plot no. | Sources of nitrogen | Acre yield of tobacco | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1925 | | | 1926 | | | 1927 | | | 1929 | | |
| | | A | B | A+B | A | B | A+B | A | B | A+B | A | B | A+B |
| | | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| 1 | Control | 490 | 520 | 505 | 220 | 360 | 290 | 110 | 300 | 205 | 0 | 0 | 0 |
| 2 | Cottonseed meal and nitrate of soda | 910 | 890 | 900 | 1,000 | 820 | 910 | 860 | 1,020 | 940 | 800 | 950 | 875 |
| 3 | Ammonium phosphate and nitrate of potash | 850 | 770 | 810 | 540 | 810 | 675 | 290 | 670 | 480 | 100 | 640 | 370 |
| 4 | Control | 420 | 420 | 420 | 310 | 290 | 300 | 120 | 220 | 170 | 0 | 0 | 0 |
| 5 | Cottonseed meal and nitrate of soda | 880 | 720 | 800 | 960 | 840 | 900 | 940 | 970 | 955 | 950 | 770 | 860 |
| 6 | Ammonium phosphate and nitrate of potash | 800 | 790 | 795 | 810 | 750 | 780 | 500 | 640 | 570 | 200 | 300 | 250 |

The two outstanding features of the results are: (1) The rapid decline in average yield from year to year obtained with the mixture of ammonium phosphate and nitrate of potash, and (2) the marked differences in rate of this decline in yield on different portions of the experimental area, as compared with the relatively uniform yields produced by a combination of nitrate of soda, cottonseed meal, superphosphate, and sulphate of potash. In the first year of the test the highly concentrated fertilizer supplying only nitrogen, phosphorus, and potassium gave rather satisfactory results, but beginning with the second year the yield on section A of plot 3 rapidly declined to the point of almost complete failure. The decline on section B of this plot was definite but much less pronounced. Rapid decline in yield first began in 1927 on section A of plot 6, closely followed by similar results on section B of this plot.

FIGURE 5.—Tobacco plants showing poor results obtained with a fertilizer consisting of nitrate of potash and monoammonium phosphate when no calcium or magnesium is added to the soil. Plot at left of measuring rod was fertilized with cottonseed meal, nitrate of soda, superphosphate, and sulphate of potash. Plot at right (four rows) received the same quantities of nitrogen, phosphoric acid, and potash, derived from nitrate of potash and monoammonium phosphate, the two rows at extreme right receiving in addition 500 pounds per acre of magnesian limestone.

In 1928 limestone containing 20 percent of magnesia was applied in the drill to two of the four rows in plots 3 and 6 at the rate of 500 pounds per acre, and this treatment was repeated in 1929. That the magnesian limestone was effective as an adjunct to the ammonium phosphate and nitrate of potash combination as a fertilizer is shown in figure 5.

These results with ammonium phosphate and nitrate of potash furnish a logical explanation of the comparatively unfavorable results obtained with Ammo-Phos and the increased yield with ammonium sulphate when additional phosphate was used in the supplementary

series discussed above. The poor results with Ammo-Phos were obtained in the early years of the experiment before the necessary quantities of calcium and magnesium were supplied in the form of magnesian limestone. Extensive observation indicates that the normal application of phosphoric acid used on the ammonium-sulphate plots was ample for crop needs, and it is believed that the beneficial effect of the additional phosphate was due to the increased supply of calcium which was thus provided.

### APPLICATION OF THE MITSCHERLICH FORMULA

Mitscherlich (*18*) in 1909 and in later years developed the theory that the relationship existing between successive increments of a growth factor and the corresponding increments of yield can be expressed mathematically by the well-known equation—

$$\frac{dy}{dx}=(A-y).\,c \tag{1}$$

in which $y$ is the increment of yield resulting from an increment $x$ of a growth factor, such as one of the essential chemical elements, $A$ is the limit toward which the yield approaches as $x$ increases indefinitely, and $c$ is a constant which is characteristic of the growth factor. According to this "effect law of growth factors" the increases in yield resulting from successive equal increments of a growth factor are proportional to the differences between the obtained yields and the maximum yield attainable. In other words, the successive increments of yield form a decreasing geometric series having a constant ratio. Thus, if the first unit of a growth factor produces 50 percent of the maximum yield obtainable the second unit will produce a further increase amounting to 50 percent of the difference between the yield from the first unit and the maximum or 25 percent, so that the total yield from the two units is 75 percent of the maximum. In the same way the third unit will produce a further increase of half the remainder of the maximum or 12.5 percent, the total yield being 87.5 percent of the maximum, and so on.

From the above equation the author derives by integration and transformation the equation—

$$log\ (A-y)=log\ A-c.x \tag{2}$$

by means of which the expected yield $y$ from a quantity $x$ of a growth factor may be computed for given values of $A$ and $c$. Where the yield produced by a soil without addition of a particular plant nutrient or fertilizer has been determined by field or pot tests under a given set of conditions, and the yield $y$ produced by a quantity $x$ of this nutrient likewise has been determined, the value of $A$ may be computed according to Mitscherlich, by a modification of equation (2)—

$$A=\frac{ky-y_o}{k-1} \tag{3}$$

in which $k=10^{c.x}$ and $y_o$ is the yield obtained when none of the plant nutrient involved is added to the soil. This method is commonly

employed by him for determining $A$ in the case of the fertilizer element nitrogen, and it presupposes of course that the numerical value of $c$ is known.

In fertilizer experiments with agricultural soils, in addition to the quantity of fertilizer $x$ added to the soil, account must be taken of the quantity of the particular element involved, which is already present in the soil. This the author does by introducing the value for the soil content of this element, designated as $b$, into equation (2):

$$log\ (A-y)=log\ A-c.\ (x+b) \tag{4}$$

When none of the fertilizer element is added to the soil $x$, of course, becomes zero so that for determining $b$, Mitscherlich employs the equation—

$$b=\frac{log\ A-log\ (A-y_o)}{c}. \tag{5}$$

After finding the values of $A$ and $b$ it is a simple matter to ascertain by means of equation (4) the expected yield for any value of $x$.

Mitscherlich's law requires that for any particular growth factor the value of $c$ be constant under all conditions, and the author himself has stated that on the soundness of this conception the whole law must stand or fall.[4] For example, the element nitrogen is said to have a constant effect value, $c$, which is independent of weather, the plant food supply of the soil, or even the character of the plant. From a very large number of pot tests Mitscherlich has arrived at the numerical value of 0.122 for $c$ in the case of the fertilizer element nitrogen. However, the author points out that $c$ can have a constant value only so long as the value for $x$ is expressed in terms of a fixed unit, and the above numerical value for $c$ in the case of nitrogen applies when $x$ represents the number of quintals of fertilizer nitrogen per hectare of land, which corresponds to approximately 90 pounds per acre.

In applying this law to the yield data for leaf and stalk and the combined yields of the two plant parts which were obtained with nitrate of soda, only the average values for a period of 10 years will be considered. These data cover the period 1919–29 except that the results for 1922 are omitted because of the very unsatisfactory yields obtained in that year. Taking 90 pounds per acre as the unit of fertilizer nitrogen, the rates of nitrogen fertilization employed, namely 10, 20, 30, 40, and 80 pounds per acre, correspond to 0.11, 0.22, 0.33, 0.44, and 0.88 units, respectively. The actual yields of leaf, stalk, and leaf and stalk combined are contained in table 9 and are shown graphically in figure 6. When the maximum possible yields, $A$, are computed by means of equation (3) with $c$ having the numerical value 0.122 the respective values obtained for leaf, stalk, and leaf and stalk combined are 5,191, 3,936, and 9,127 pounds per acre. By means of equation (5) the indicated quantity of reserve nitrogen in the soil, $b$, is found to be 41.4 pounds per acre when leaf-yield data are considered and 30.3 pounds when yields of stalk are

[4] Since this bulletin was prepared for publication there has appeared an article by the late W.J.Spillman (U.S. Dept. Agr. Tech. Bull. 348. Use of the Exponential Yield Curve in Fertilizer Experiments, 1933) in which the author expresses the view that Mitscherlich's values for c are not always applicable to the results of field experiments in the United States and new values must be obtained for each new set of conditions.

considered, the mean value being about 36 pounds. The expected yields for the several rates of fertilization are determined by introducing into equation (4) the values for $A$ and $b$ (table 9 and fig. 6).

TABLE 9.—*Actual average yields of leaf and of stalk and the two combined for a period of 10 years and the corresponding theoretical yields computed by the Mitscherlich equation, using as base values the actual yields at three rates of fertilization and two numerical values for the constant c; including in each case the computed maximum possible yield A, and the quantity of the soil's reserve supply of nitrogen b*

YIELDS OF LEAF PER ACRE

| Quantity of fertilizer nitrogen used per acre | | Actual yield per acre | Computed yields, using as base values the actual yields with— | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 10 pounds of nitrogen per acre | | | | 40 pounds of nitrogen per acre | | | | 80 pounds of nitrogen per acre | | | |
| | | | $c$=0.122 | | $c$=1.2 | | $c$=0.122 | | $c$=1.2 | | $c$=0.122 | | $c$=1.2 | |
| Pounds | Units | | Value obtained | Excess (+) or deficit (−) | Value obtained | Excess (+) or deficit (−) | Value obtained | Excess (+) or deficit (−) | Value obtained | Excess (+) or deficit (−) | Value obtained | Excess (+) or deficit (−) | Value obtained | Excess (+) or deficit (−) |
| | | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| 0 | 0 | 629 | (629) | ------ | (629) | ------ | (629) | ------ | (629) | ------ | (629) | ------ | (629) | ------ |
| 10 | .11 | 768 | (768) | ------ | (768) | ------ | 727 | −41 | 769 | +1 | 699 | −69 | 774 | +6 |
| 20 | .22 | 893 | 903 | +10 | 871 | −22 | 822 | −71 | 872 | −21 | 767 | −124 | 881 | −12 |
| 30 | .33 | 986 | 1,033 | +47 | 947 | −39 | 914 | −72 | 948 | −38 | 833 | −153 | 960 | −26 |
| 40 | .44 | 1,004 | 1,159 | +155 | 1,003 | −1 | (1,004) | ------ | (1,004) | ------ | 897 | −107 | 1,018 | +14 |
| 80 | .88 | 1,134 | 1,629 | +495 | 1,113 | −21 | 1,335 | +201 | 1,115 | −19 | (1,134) | ------ | (1,134) | ------ |
| | $A$ | | 5,191 | | 1,160 | | 3,853 | | 1,162 | | 2,934 | | 1,182 | |
| | $b$ | | 41.4 | | 25.5 | | 57.0 | | 25.4 | | 77.3 | | 24.8 | |

YIELDS OF STALK PER ACRE

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 355 | (355) | ------ | (355) | ------ | (355) | ------ | (355) | ------ | (355) | ------ | (355) | ------ |
| 10 | .11 | 464 | (464) | ------ | (464) | ------ | 446 | −18 | 485 | +21 | 411 | −53 | 472 | +8 |
| 20 | .22 | 622 | 570 | −52 | 544 | −78 | 534 | −88 | 581 | −41 | 466 | −156 | 557 | −65 |
| 30 | .33 | 665 | 672 | +7 | 604 | −61 | 619 | −46 | 651 | −14 | 519 | −146 | 621 | −44 |
| 40 | .44 | 703 | 772 | +69 | 648 | −55 | (703) | ------ | (703) | ------ | 571 | −132 | 668 | −35 |
| 80 | .88 | 761 | 1,140 | +379 | 734 | −27 | 1,009 | +248 | 807 | +46 | (761) | ------ | (761) | ------ |
| | $A$ | | 3,936 | | 771 | | 3,351 | | 850 | | 2,208 | | 800 | |
| | $b$ | | 30.3 | | 20.0 | | 36.0 | | 17.6 | | 56.2 | | 19.1 | |

YIELDS OF LEAF AND STALK COMBINED PER ACRE

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 984 | (984) | ------ | (984) | ------ | (984) | ------ | (984) | ------ | (984) | ------ | (984) | ------ |
| 10 | .11 | 1,232 | (1,232) | ------ | (1,232) | ------ | 1,174 | −58 | 1,253 | +21 | 1,111 | −121 | 1,246 | +14 |
| 20 | .22 | 1,515 | 1,472 | −43 | 1,416 | −99 | 1,357 | −158 | 1,451 | −64 | 1,233 | −282 | 1,439 | −76 |
| 30 | .33 | 1,651 | 1,705 | +54 | 1,551 | −100 | 1,535 | −116 | 1,598 | −53 | 1,352 | −299 | 1,581 | −70 |
| 40 | .44 | 1,707 | 1,931 | +224 | 1,650 | −57 | (1,707) | ------ | (1,707) | ------ | 1,468 | −239 | 1,687 | −20 |
| 80 | .88 | 1,895 | 2,768 | +873 | 1,848 | −47 | 2,346 | +451 | 1,921 | +26 | 1,895 | ------ | 1,895 | ------ |
| | $A$ | | 9,127 | | 1,931 | | 7,204 | | 2,011 | | 5,143 | | 1,983 | |
| | $b$ | | 36.5 | | 23.2 | | 47.0 | | 21.9 | | 68.0 | | 22.3 | |

In the above computations the increases in yield resulting from the first 10 pounds of fertilizer nitrogen are used as base values in determining $A$ and $b$. When the increases in yield obtained with higher rates of fertilization are employed for the computations progressively lower values for $A$ and correspondingly higher values for $b$ are

obtained. As regards the data for the leaf, this discrepancy can be removed only by greatly increasing the numerical value of $c$, as, for

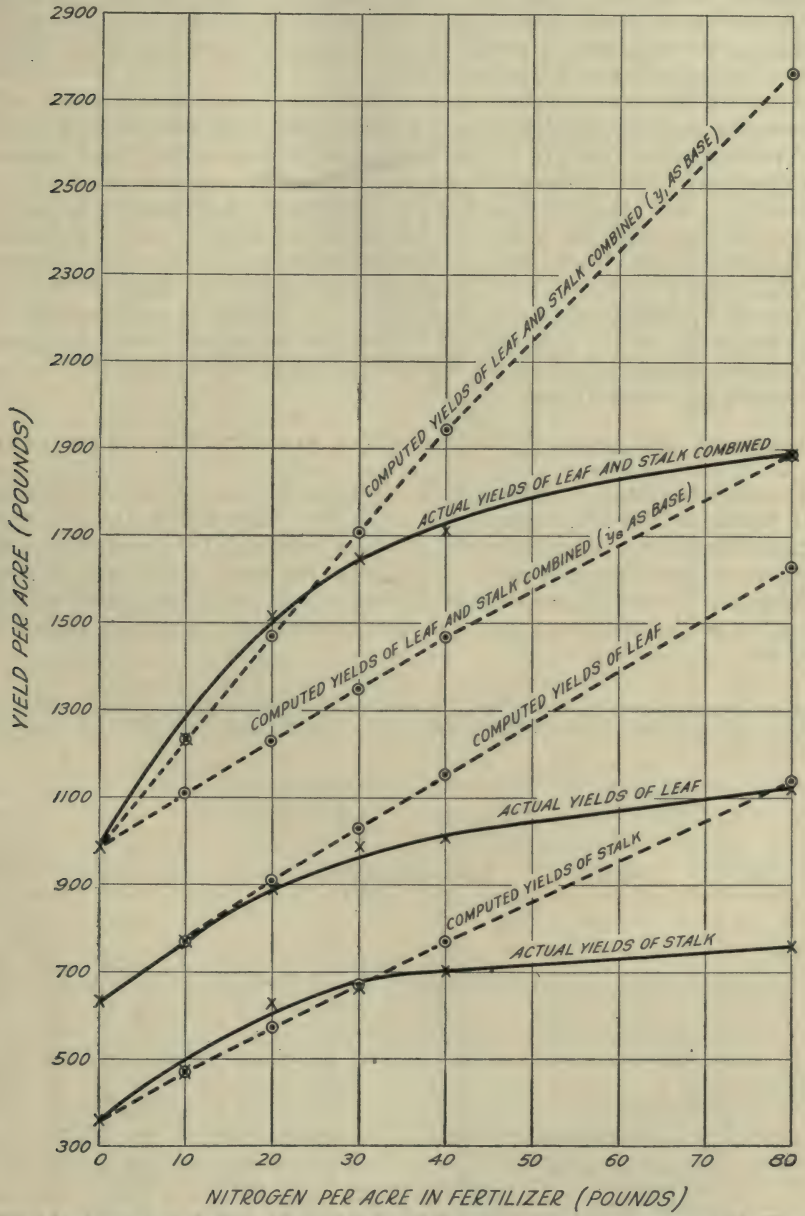


FIGURE 6.—Average actual yields of leaf and stalk and the two combined at various rates of fertilization with nitrogen for a period of 10 years, and the corresponding theoretical yields computed by means of the Mitscherlich formula, using 0.122 as the numerical value of the proportionality factor, $c$, of the Mitscherlich equation. The increases in yield obtained from the first 10 pounds of fertilizer nitrogen per acre ($y_1$) were used as base values in the computations, as was also the increase from 80 pounds of nitrogen ($y_8$) in case of the leaf and stalk combined.

example, by raising it to 1.2, which is 10 times the value assigned to it by Mitscherlich. In this case the maximum yield obtainable, $A$, is

reduced to slightly less than 1,200 pounds, and the value for the effective supply of nitrogen in the soil, $b$, is lowered to about 25 pounds. With this value for $c$ the computed yields for the various rates of fertilization also agree fairly well with the actual yields, although the theoretical yields for the intermediate rates of fertilization are somewhat too low (table 9).

As to the data for the stalk, no value for $c$ has been found which will give consistent figures for $A$ and $b$ when the yields at different rates of fertilization are used in the calculations. On the whole, best results are obtained when $c$ is assigned a numerical value approximating unity. However, this value of $c$ does not give satisfactory agreement between the computed and the actual yields for the several rates of nitrogen fertilization. For leaf and stalk combined there is only a fair degree of consistency in the values of $A$ and $b$ obtained by using the yields produced by different rates of fertilization in making the computations and assigning to $c$ a value of 1.2. The differences between the computed and the actual yields for the several rates of fertilization in some instances are rather large.

## INFLUENCE OF NITROGEN SUPPLY ON MARKET VALUE OF LEAF

In order to obtain reliable information on the comparative commercial value of the crops produced with the different quantities and forms of nitrogen, representative samples were laid before experienced buyers of Maryland tobacco each year for their valuation of the product. The value per acre and the average price per pound of the crop for each treatment as thus determined are shown in tables 7 and 10.

TABLE 10.—*Acre value and average price per pound of tobacco in primary series of tests with nitrogen applied at different rates and derived from different sources, 1919–29*

| Plot no. | Nitrogen applied | | Acre value (dollars) | | | | | | | | | | | 10-year average [1] price per pound |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity per acre | Source | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | Average |
| | *Lb.* | | | | | | | | | | | | | *Cents* |
| 1 | 0 | | 162 | 133 | 95 | 61 | 189 | 104 | 115 | 145 | 93 | 67 | 125 | 119 | 17 |
| 2 | 20 | Cyanamide | 240 | 227 | 109 | 101 | 268 | 249 | 195 | 168 | 143 | 113 | 164 | 173 | 21 |
| 3 | 20 | Ammonium nitrate | 260 | 259 | 147 | 103 | 293 | 176 | 199 | 184 | 257 | 137 | 151 | 199 | 23 |
| 4 | 20 | Ammonium sulphate | 256 | 288 | 133 | 129 | 269 | 174 | 215 | 163 | 219 | 123 | 148 | 194 | 23 |
| 5 | 0 | | 134 | 108 | 86 | 25 | 193 | 90 | 83 | 107 | 86 | 55 | 91 | 97 | 16 |
| 6 | 20 | Ammonium chloride | 198 | 185 | 63 | 170 | 259 | 236 | 209 | 197 | 75 | 133 | 135 | 164 | 18 |
| 7 | 20 | Nitrate of soda | 204 | 227 | 163 | 121 | 237 | 186 | 238 | 142 | 205 | 119 | 145 | 180 | 21 |
| 8 | 10 | do | 207 | 213 | 104 | 46 | 167 | 149 | 152 | 101 | 112 | 101 | 135 | 134 | 18 |
| 9 | 0 | | 123 | 102 | 81 | 20 | 159 | 61 | 88 | 91 | 67 | 42 | 69 | 84 | 15 |
| 10 | 30 | Nitrate of soda | 249 | 277 | 209 | 91 | 360 | 202 | 218 | 167 | 208 | 119 | 159 | 206 | 22 |
| 11 | 40 | do | 227 | 340 | 222 | 93 | 281 | 188 | 252 | 167 | 170 | 121 | 134 | 201 | 21 |
| 12 | 40 | Ammonium sulphate | 292 | 358 | 221 | 104 | 270 | 103 | 210 | 209 | 177 | 144 | 159 | 214 | 23 |
| 13 | 0 | | 133 | 87 | 88 | 20 | 177 | 57 | 84 | 101 | 76 | 45 | 78 | 89 | 15 |
| 14 | 40 | Ammonium chloride | 231 | 242 | 191 | 108 | 199 | 283 | 227 | 192 | 137 | 142 | 96 | 177 | 18 |
| 15 | 40 | Ammonium nitrate | 327 | 401 | 272 | 112 | 290 | 219 | 240 | 222 | 146 | 129 | 144 | 228 | 22 |
| 16 | 40 | Cyanamide | 254 | 289 | 117 | 80 | 157 | 185 | 184 | 206 | 155 | 78 | 115 | 164 | 19 |
| 17 | 0 | | 134 | 118 | 117 | 18 | 176 | 69 | 98 | 97 | 32 | 39 | 59 | 89 | 16 |
| 18 | 80 | Nitrate of soda | 230 | 261 | 202 | 35 | 262 | 167 | 175 | 144 | 214 | 123 | 163 | 181 | 17 |
| 19 | 80 | Ammonium sulphate | 332 | 345 | 138 | 28 | 146 | 86 | 230 | 232 | 165 | 139 | 95 | 185 | 17 |
| 20 | 80 | Ammonium chloride | 267 | 249 | 55 | 27 | 87 | 124 | 74 | 142 | 96 | 131 | 99 | 123 | 11 |
| 21 | 0 | | 143 | 138 | 89 | 21 | 139 | 40 | 85 | 84 | 31 | 39 | 54 | 82 | 14 |
| Average | | | 219 | 231 | 138 | 72 | 218 | 150 | 170 | 155 | 136 | 102 | 120 | 156 | |

[1] Results for 1924 are not included in the 10-year average.

All rates of application of nitrogen increased the gross value of the crop over that of the control plots. Considering the data with nitrate of soda, the first 10 pounds of nitrogen per acre gave an increase in value of $50 per acre, the second 10 pounds a further increase of $46, while the third 10 pounds gave the maximum value, representing an additional gain of $26. There was no significant difference in value of crop between the 30- and the 40-pound rates of fertilizing, but there was a material decrease in crop value with the use of 80 pounds of nitrogen per acre. Substantially the same relationships obtain with respect to price per pound of the tobacco. All sources of nitrogen except cyanamide gave somewhat higher gross values per acre at the 40-pound rate than at the 20-pound rate, but differences in price per pound of the leaf were hardly large enough to be significant. The effects of the 80-pound rate were the same with ammonium sulphate as with nitrate of soda, but with ammonium chloride the decreases in value per acre and price per pound of leaf were much more marked.

The effects of the different sources of nitrogen on the price per pound of the tobacco leaf and their action in increasing the gross value of the crop per acre are summarized in table 11. The average price per pound of the crop on the control plots receiving no nitrogen was 15.5 cents in the primary series and 12.5 cents in the supplementary series. The corresponding gross crop values per acre were $93 and $62, respectively. In the primary series, ammonium nitrate and ammonium sulphate gave the best quality of tobacco at both the 20- and the 40-pound rates of fertilizing, and the ammonium nitrate gave slightly higher crop values per acre than the sulphate. Nitrate of soda ranked next in value per pound and gross value per acre of the crop produced. Cyanamide produced a fairly good quality of leaf at the 20-pound rate while with ammonium chloride a comparatively poor quality was produced at all rates of fertilizing. Until rather recently it has not been the practice of buyers in southern Maryland to determine the burning qualities of tobacco in estimating its market value, the assumption being that all tobacco having the desired color and texture will burn satisfactorily. Consequently, the values shown in table 11 were arrived at independently of the factor of combustibility. But for this circumstance the market value of the tobacco grown with ammonium chloride would have been placed considerably lower.

In the supplementary series urea and ammonium sulphate at either rate of fertilizing did not differ materially in quality of the tobacco produced, but at the higher rate of fertilizing with ammonium sulphate an increased rate of application of calcium phosphate was necessary to obtain best results as to value of crop per acre. The reason for this situation has already been given. The somewhat poorer showing of Ammo-Phos is due primarily to the reduced growth obtained in the early years of the test before dolomitic limestone had been applied. After calcium and magnesium had thus been added to the soil Ammo-Phos gave good results.

TABLE 11.—*Increase in value per acre and in the estimated value per pound of tobacco leaf in the primary and supplementary series of tests obtained with nitrogen derived from different forms and applied at different rates*

[The last plot in the supplementary series received a double ration of phosphoric acid]

| Series of test and source of nitrogen | Increase in acre value of crop | | | Average value per pound of leaf | | |
|---|---|---|---|---|---|---|
| | 20 pounds nitrogen | 40 pounds nitrogen | 80 pounds nitrogen | 20 pounds nitrogen | 40 pounds nitrogen | 80 pounds nitrogen |
| Primary series: | *Dollars* | *Dollars* | *Dollars* | *Cents* | *Cents* | *Cents* |
| Cyanamide | 80 | 71 | ---------- | 21 | 19 | ---------- |
| Ammonium nitrate | 106 | 135 | ---------- | 23 | 22 | ---------- |
| Ammonium sulphate | 101 | 121 | 92 | 23 | 23 | 17 |
| Ammonium chloride | 71 | 84 | 30 | 18 | 18 | 11 |
| Nitrate of soda | 97 | 108 | 88 | 21 | 21 | 17 |
| Supplementary series: | | | | | | |
| Urea | 97 | 151 | ---------- | 20 | 21 | ---------- |
| Ammonium sulphate | 96 | 134 | ---------- | 21 | 21 | ---------- |
| Ammo-Phos | 82 | 125 | ---------- | 19 | 21 | ---------- |
| Ammonium sulphate | ---------- | 154 | ---------- | ---------- | 22 | ---------- |

## RELATION OF NITROGEN SUPPLY TO RATE AND TYPE OF GROWTH

### LEAF, STALK, AND ROOT GROWTH

In 1927, data on air-dried weights of leaf, stalk, and root were obtained on 20 plants in a control treatment and in the plots receiving nitrogen in the form of nitrate of soda at each rate included in the primary series. The mature plants were harvested by cutting the stalk at the ground level, and the weights of leaf and stalk were obtained after the curing process was completed. After harvest the roots were carefully dug, washed with water, and allowed to dry in the air under shelter. It was not possible to make complete recovery of the roots, and the data for this part of the plant are only approximately correct. The percentages of leaf, stalk, and root thus obtained are shown in table 12.

TABLE 12.—*Percentages of air-dried leaf, stalk, and root in plants receiving different quantities of nitrogen, crop of 1927*

| Plot no. | Nitrogen applied per acre | Percentages of plant parts | | | Plot no. | Nitrogen applied per acre | Percentages of plant parts | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Leaf | Stalk | Root | | | Leaf | Stalk | Root |
| | *Pounds* | *Percent* | *Percent* | *Percent* | | *Pounds* | *Percent* | *Percent* | *Percent* |
| 9 | 0 | 68.5 | 16.5 | 15.0 | 10 | 30 | 63.1 | 22.0 | 14.9 |
| 8 | 10 | 64.3 | 19.4 | 16.3 | 11 | 40 | 61.9 | 23.1 | 15.0 |
| 7 | 20 | 65.4 | 20.9 | 13.7 | 18 | 80 | 66.3 | 20.5 | 13.2 |

The range in percentage of root under the different treatments is rather narrow and does not indicate any clearly defined effect of increasing quantities of nitrogen in the fertilizer. The difference in proportions of leaf and stalk are more definite and are pretty well in line with the much more comprehensive data contained in table 5. The proportions of leaf obtained with increasing quantities of nitrogen derived from nitrate of soda, ammonium sulphate, and ammonium chloride, expressed as percentages of the combined weight of cured leaf and stalk, are shown graphically in figure 7. The source of the

nitrogen affects somewhat the proportions of leaf and stalk. At all rates used, ammonium sulphate gave the lowest percentage of leaf. Reference has already been made to the stimulating action of the chloride ion on leaf development, and it will be seen that ammonium chloride has given the highest percentage of leaf of all the forms of nitrogen tested. The sharp rise in percentage of leaf with the 80-pound rate of fertilizing is especially noticeable.

The annual average yields of leaf and stalk for all treatments, as shown in table 5, demonstrate that weather conditions also may have a marked effect on the proportions of leaf and stalk. In general, in years of low crop yield there is a tendency toward a high percentage of leaf, and in years of high crop yield the tendency is toward a high percentage of stalk. This is equally true for the control plots receiving no nitrogen and those well supplied with this element. It appears

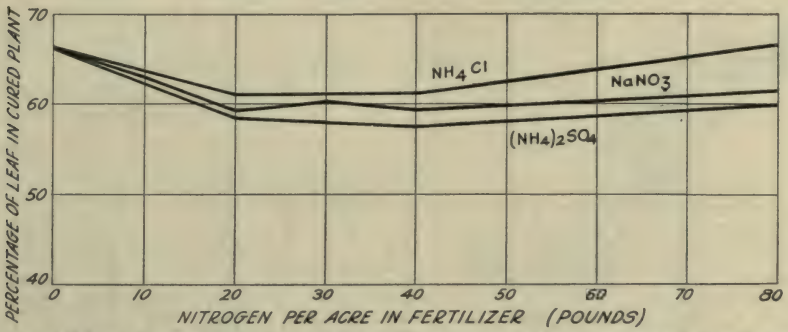


FIGURE 7.—Effects of quantity and source of the fertilizer nitrogen on the proportions of leaf and stalk in the cured plant. Nitrogen deficiency and a high nitrogen supply alike produce a small stalk as compared with a moderate supply of nitrogen. A stimulating action of the chloride ion on leaf development is shown by the results with ammonium chloride, while ammonium sulphate apparently tends to produce a relatively large stalk.

that environmental conditions exert a somewhat greater effect on the yield of stalk than on the yield of leaf.

To obtain information as to the effect of the supply of nitrogen on the proportions of midrib and lamina or web in the leaf, observations were made on samples of the cured crop of 1929 from the nitrate of soda plots receiving nitrogen at the rates of 20, 40, and 80 pounds per acre and the control plots which received no nitrogen. In the leaf from the latter plots the percentage of midrib was 27.1 and from the plots receiving 20, 40, and 80 pounds of nitrogen per acre the respective values were 29.3, 31.1, and 27.8. These results were confirmed in additional tests. Thus, the maximum percentage of midrib is obtained with a moderate supply of nitrogen, and either a very low or a high supply tends to reduce the relative weight of the midrib. In these experiments it was observed that the percentage of midrib is decidedly lower in the lower leaves of the plant than in the middle and upper leaves.

### THE GROWTH RATE

In 1920 and again in 1926 observations were made on the rate of increase in height of selected plants in the primary series of plots. Since the results in the 2 years were about the same, only the 1926 data need be considered here. In a control plot and the plots receiving 20, 40, and 80 pounds of nitrogen from nitrate of soda and 40 pounds

from ammonium sulphate, ammonium nitrate, and ammonium chloride, respectively, two groups of plants were selected for study. One group representing each treatment consisted of 25 larger plants which had obtained an early start, while the other group contained 14 smaller plants, and measurements of height were made at intervals of 9 to 15 days. The results are shown in table 13. At the time of last measurement of total height none of the plants in either group receiving no nitrogen had flowered, but in all other instances many of the plants were in bloom.

TABLE 13.—*Effects of nitrogen derived from different sources and applied at different rates on the average rate of increase in height, the number of leaves, and the length of internodes of 25 larger and 14 smaller tobacco plants, season of 1926*

| Number and size of plants | Nitrogen applied | | Average total height on— | | | | | Average final height to first leafless sucker | Average number of leaves | Average length of internodes |
|---|---|---|---|---|---|---|---|---|---|---|
| | Quantity per acre | Source | July 23 | Aug. 2 | Aug. 11 | Aug. 26 | Sept. 4 | | | |
| | *Pounds* | | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* | *Inches* | | *Inches* |
| 25 larger | 0 | | 5.7 | 9.8 | 14.5 | 27.7 | | 40.2 | 34 6 | 1.16 |
| | 20 | Nitrate of soda | 6.0 | 16.0 | 28.8 | 56.1 | | 40.8 | 27.2 | 1.48 |
| | 40 | do | 5.7 | 14.6 | 26.1 | 53.2 | | 42.6 | 27.2 | 1.55 |
| | 40 | Ammonium sulphate | 5.9 | 16.4 | 28.8 | 54.8 | | 42.4 | 27.2 | 1.57 |
| | 40 | Ammonium chloride | 5.8 | 14.9 | 27.1 | 52.7 | | 41.8 | 26.2 | 1.60 |
| | 40 | Ammonium nitrate | 5.9 | 15.5 | 29.2 | 54.5 | | 40.6 | 27.3 | 1.49 |
| | 80 | Nitrate of soda | 5.1 | 12.9 | 23.2 | 50.9 | | 43.1 | 28.0 | 1.54 |
| 14 smaller | 0 | | 2.9 | 5.0 | 8.5 | 18.0 | 21.0 | 32.8 | 34.9 | .94 |
| | 20 | Nitrate of soda | 2.5 | 7.8 | 15.6 | 33.9 | 43.9 | 41.0 | 28.3 | 1.45 |
| | 40 | do | 2.8 | 8.6 | 16.9 | 38.1 | 41.4 | 43.0 | 27.5 | 1.57 |
| | 40 | Ammonium sulphate | 3.0 | 9.0 | 17.4 | 36.1 | 47.3 | 42.5 | 28.4 | 1.48 |
| | 40 | Ammonium chloride | 2.8 | 8.9 | 18.0 | 40.5 | 52.2 | 44.4 | 27.4 | 1.60 |
| | 40 | Ammonium nitrate | 3.0 | 10.3 | 19.1 | 43.1 | 55.6 | 42.6 | 27.9 | 1.53 |
| | 80 | Nitrate of soda | 2.3 | 7.4 | 13.9 | 32.9 | 44.7 | 44.6 | 31.1 | 1.43 |

With no nitrogen supplied in the fertilizer the increase in height was at a slow rate while, on the whole, the most rapid rate was obtained with 40 pounds of nitrogen per acre in case of the smaller plants (fig. 8) and with 20 pounds of nitrogen per acre in the case of the larger plants. In both instances the rate of growth with 80 pounds of nitrogen was slightly less than with the lower rates of nitrogen fertilization, particularly in the early stages. The effects on the growth rate produced by differences in the form of nitrogen used were comparatively small. The final height of the stalk measured up to the position of the lowermost leafless branch increased somewhat with increase in the nitrogen supply. The data on increase in size of the leaf in the 1929 crop indicate that according to this method of measurement the intermediate and the highest rates of nitrogen fertilization produced about the same rate of growth in the later stages of leaf development. (See table 20.) It is apparent, however, that the maximum application of nitrogen produced the maximum rate of increase in size of leaf in the earlier stages of growth.

### NUMBER, SIZE, AND SHAPE OF LEAVES

Counts were made of the total number of leaves produced per plant in the two groups of individuals used in the study of growth rate. The first counts were made in the early stages of growth so as to

avoid overlooking lower leaves which would disappear before the plants had reached maturity. All leaves up to and including the position of the lowermost leafless sucker or lateral branch were counted. The results are shown in table 13.

It will be seen that the delayed growth and flowering in the no-nitrogen treatments are associated with a definite increase in the number of leaves per plant, accompanied by a decrease in length of the internodes. Also, the 80-pound rate of nitrogen fertilization in comparison with lower rates produced a slight increase in number of leaves per plant in association with delayed growth and flowering.

In 1919, 1920, and 1923, measurements of length and width of leaves located at the center of the plant were made on 25 selected individuals in each of the plots receiving 20, 40, and 80 pounds of nitrogen as nitrate of soda, respectively, and in the controls. Measurements were made at time of topping on one series of leaves, about 2 weeks after topping on a second series of leaves immediately above the first series, and about 4 weeks after topping on a third series directly above the second series on the plant. Similar observations had been made in 1918 in another nitrogen test conducted on the same general plan and located on the same soil type. It is known that the area of a tobacco leaf is approximately two thirds the product of the length and the width, and this formula was used to compute the leaf areas for comparison. To arrive at the effect of the nitrogen supply on the general shape of the leaf the ratio between the length and width was used. The averaged results for size and shape of leaf under the different treatments for the 4 years mentioned are shown in table 14. This table also contains data on observations made in 1929 on the effects of the nitrogen supply on the area of upper, middle, and lower leaves of the plant. The leaves used for the purpose were those employed for determining the relative weight per square foot as affected by the nitrogen supply (p. 29).

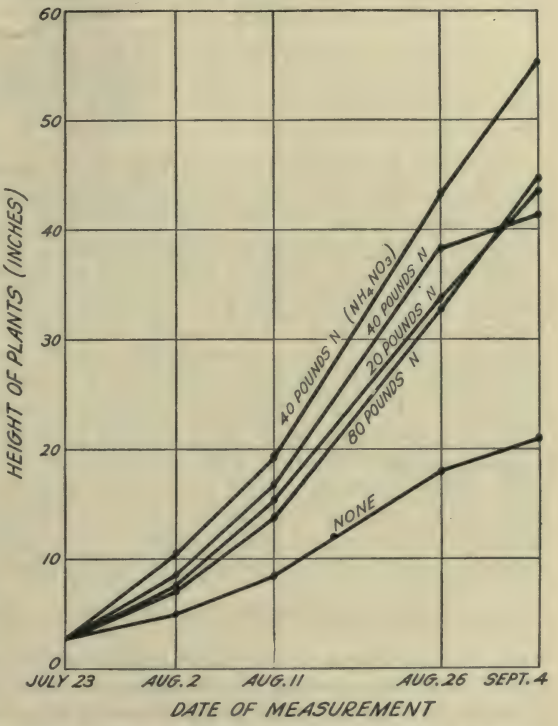


FIGURE 8.—Effect of the supply of fertilizer nitrogen on the growth rate as measured by increase in height. For the period covered, the growth rate of only the plants receiving no nitrogen and those receiving 40 pounds per acre from nitrate of soda show the typical sigmoid form of curve. Ammonium nitrate, supplying both ammonia and nitrate nitrogen, produced the most rapid rate of growth, while 40 pounds of nitrogen from nitrate of soda caused more rapid growth than 80 pounds.

TABLE 14.—*Effects of nitrogen applied at different rates as a fertilizer on the length, width, and area, and the ratio of length to width of green tobacco leaves in different years*

| Quantity of nitrogen applied per acre (pounds) | Average shape and size of leaf, 1918–20, 1923 | | | | Area of leaves at different positions on stalk, 1929 | | | |
|---|---|---|---|---|---|---|---|---|
| | Length | Width | Ratio of length to width | Area | Upper leaf | Middle leaf | Lower leaf | Average |
| | *Inches* | *Inches* | | *Sq. in.* | *Sq. in.* | *Sq. in.* | *Sq. in.* | *Sq. in.* |
| 0 | 17.65 | 8.17 | 2.17 | 96.7 | 71.4 | 99.9 | 104.8 | 92.0 |
| 20 | 21.11 | 10.35 | 2.05 | 146.0 | 68.5 | 145.2 | 146.1 | 119.9 |
| 40 | 21.17 | 10.70 | 1.98 | 152.4 | 87.4 | 171.1 | 156.0 | 138.2 |
| 80 | 23.45 | 12.50 | 1.88 | 197.9 | | | | |

Increase in the nitrogen supply has a marked effect in increasing the size of the leaf, the area per leaf produced by the 80-pound rate being double that of the controls. The increase produced by the 40-pound rate over that of the 20-pound rate, however, is relatively small except in the middle and upper leaves of 1929. As the nitrogen supply is increased the leaf becomes progressively broader in proportion to length. To compare the effects of nitrate and ammonia nitrogen, observations were made in 1919, 1920, and 1923 on leaf dimensions in the plots receiving 40 pounds of nitrogen as ammonium sulphate. For the 3 years the average area per leaf obtained with the ammonia nitrogen was 141.7 square inches as compared with 143.1 square inches obtained with 40 pounds of nitrogen from nitrate of soda. The corresponding values for ratio of length to width of leaf were 2.06 and 2.09, respectively. It appears, therefore, that there was no difference of importance in the effects of the two forms of nitrogen on the dimensions of the leaf produced.

### WEIGHT AND THICKNESS OF LEAF AND SPECIFIC GRAVITY OF LEAF MATERIAL

In 1929, groups of 20 plants each were selected on the plots receiving 20 and 40 pounds of nitrogen per acre in the fertilizer and on a control plot in order to make observations on effect of the nitrogen supply on the weight of leaf per unit of area after completion of the curing. The plants were topped in the usual manner, and just before harvest the length and width of an upper, middle, and lower leaf on each of the selected plants were measured and the area computed. The upper leaf in each instance was located approximately in the center of the upper third portion of the leaves of the plant, and the lower leaf likewise was located at or near the center of the lower third portion of the leaves. The plants were harvested and cured without removing the leaves from the stalks. After ascertaining the dry weight of the cured leaves the average weight per square foot of each lot was calculated. The results are shown in table 15.

TABLE 15.—*Effects of nitrogen applied as a fertilizer at different rates on the weight per square foot, the thickness and the specific gravity of cured tobacco leaves, crop of 1929*

| Quantity of nitrogen applied per acre (pounds) | Weight of cured leaf per square foot | | | | Average thickness of middle leaves in hundredths of a millimeter, measured with— | | Specific gravity of the powdered leaf material | | |
|---|---|---|---|---|---|---|---|---|---|
| | Upper leaf | Middle leaf | Lower leaf | Average | Large spindle head | Small spindle head | Upper leaf | Middle leaf | Lower leaf |
| | *Grams* | *Grams* | *Grams* | *Grams* | | | | | |
| 0 | 5.458 | 5.499 | 6.495 | 5.817 | 50 | 26 | 1.4766 | 1.4966 | 1.5056 |
| 20 | 5.602 | 4.795 | 5.848 | 5.415 | 39 | 27 | 1.4549 | 1.4953 | 1.5175 |
| 40 | 4.979 | 4.356 | 5.744 | 5.026 | 36 | 22 | 1.4607 | 1.4839 | 1.5350 |
| 80 | | | | | 28 | 20 | | | |

The data in table 15 show that increase in the supply of fertilizer nitrogen results in a decrease in weight of a unit area of the leaf. This effect is produced alike in the lower, middle, and upper leaves of the plant. Confirmatory data are contained in the section of this bulletin dealing with processes of nutrition and metabolism. (See tables 20 and 32.)

It is a matter of some importance to know whether decrease in thickness of the leaf lamina is entirely responsible for the decided decrease in weight per unit area brought about by the high nitrogen supply but, unfortunately, no entirely satisfactory method of measuring the thickness of the cured leaf has been found. The leaf, after curing, presents an extremely uneven surface, and it is difficult to obtain consistent results in measurements made with a micrometer caliper. The readings obtained are greatly influenced by the moisture content of the leaf and by the size of the head of the measuring spindle of the instrument. Most work on the subject has been done with moist material, but in this state the tissues are easily compressed so that even with the lowest pressures that can be employed the readings are decidedly lower than when the material is measured in a dry condition. In the experience of the writers, best results are obtained with dry material. The apparent thickness is, of course, that of the fine network of veins in the leaf lamina, and naturally, when the head of the measuring spindle is small and precautions are taken to avoid the veins which are readily visible, lower readings will be obtained than when a measuring spindle with relatively large head is used. A large number of measurements were made with air-dried cured-leaf samples of the 1929 crop from the plots employed in the study of the weight of leaf per square foot as affected by the nitrogen supply. The leaves were taken from the middle portion of the plants. For the measurements, a micrometer dial gage reading to one hundredth of a millimeter, such as is used in measuring thickness of paper, was employed. Comparative measurements were made with spindle heads of approximately 13 and 6 millimeters diameter. It is well known that different portions of an individual leaf vary materially in thickness, the apical and marginal portions being decidedly thicker than the basal and interior parts (*14*). In the present case, readings were taken on small disks cut from various parts of the leaf and the results were averaged for the entire leaf. The final data are given in table 15

While the results are not entirely consistent, as a whole, they indicate that the reduced weight per unit area obtained with an increased supply of nitrogen is due at least in part to decrease in thickness of the leaf. The apparent decrease in the differences in thickness of leaf from the various treatments obtained with the smaller spindle head of the measuring instrument suggests that the vascular tissues are more prominent in the leaf grown with a low nitrogen supply. Doubtless the fine network of vascular tissue in the leaf plays a prominent part in the judgment formed by the expert tobacco buyer as to the so-called body and texture of the cured product. In any case, it is hardly possible to avoid the effects of the smaller veins in making direct measurements of leaf thickness by such methods as here employed, but the results have value from a practical standpoint, at least for comparative purposes. Since the material was measured in an air-dry condition the values obtained are higher than those reported by most other investigators for leaf thickness.

A limited number of observations were made on the apparent specific gravity of the ground-cured leaf material, using the samples from the 1929 crop that had been employed in the study of weight per unit area of the leaf. The determination was made simply by measuring the volume of toluol displaced by a known weight of the leaf material at 25° C., employing for the purpose the usual type of picnometer. Toluol was used because of its slight solvent action on the constituents of tobacco. To facilitate removal of air from within and about the leaf particles, the apparatus was placed under a partial vacuum before completing the filling with toluol. A correction was applied for moisture content and adherent earthy matter of the air-dried sample. The results expressed as weight per cubic centimeter of the tobacco are contained in table 15. As compared with differences in weight per unit of area, the apparent differences in specific gravity or density of the solids of the leaf are very small. Assuming that the toluol effectively penetrated the leaf tissues, these values, of course, throw no light on the relative development of intercellular air spaces in the tissues of the leaf under the different nitrogen treatments.

### TIME OF FLOWERING AND RIPENING OF LEAF

The terminal flower bud is normally the first to open on the tobacco plant, and its opening marks a definite stage of development which is easily observed. No personal equation is involved in determining the date of its opening, and for comparative purposes the appearance of this blossom furnishes a convenient point from which to reckon relative stages of development in the plant. It is recognized, however, that the opening of the terminal flower bud does not necessarily indicate a fixed stage of development of any particular leaf on the plant. Its significance attaches rather to developmental stage of the plant as a whole. Throughout this bulletin data on time of flowering and, with certain exceptions, the time of topping are based on the time of opening of the terminal blossom unless otherwise stated.

In the 4 years, 1919–22, observations were made on date of flowering of all individuals in each treatment of the primary series of plots. The counts were made at intervals of 3 days, and the plants were topped as they flowered. When 80 to 85 percent of all plants in the series had flowered, the remaining ones were topped without regard to stage of development. The data on flowering for the 4 years were

assembled in three groups: (1) Number of plants which had flowered up to 20 days before the final topping; (2) number which flowered in the 20 days immediately preceding the final topping; (3) number which had failed to flower at final topping. The results expressed in percentages of the total number of plants in each treatment are shown in table 16.

TABLE 16.—*Average effect of varying quantities and forms of nitrogen applied in the fertilizer on time of flowering of tobacco, 1919–22*

| Plot no. | Nitrogen applied | | Plants flowering— | | Plants not flowering prior to final topping |
|---|---|---|---|---|---|
| | Quantity per acre | Source | 20 to 40 days prior to final topping | During 20 days immediately preceding final topping | |
| | *Pounds* | | *Percent* | *Percent* | *Percent* |
| 1, 5, 9, 13, 17, 21 | None | | 8.2 | 29.8 | 62.0 |
| 8 | 10 | Nitrate of soda | 17.4 | 47.6 | 35.0 |
| 7 | 20 | do | 28.1 | 54.6 | 17.3 |
| 10 | 30 | do | 36.4 | 43.2 | 10.4 |
| 11 | 40 | do | 37.8 | 46.9 | 15.3 |
| 18 | 80 | do | 31.3 | 50.6 | 18.1 |
| 4 | 20 | Ammonium sulphate | 55.1 | 34.4 | 10.5 |
| 12 | 40 | do | 67.1 | 24.0 | 8.9 |
| 19 | 80 | do | 49.4 | 42.1 | 8.5 |
| 6 | 20 | Ammonium chloride | 43.7 | 41.2 | 15.1 |
| 14 | 40 | do | 61.9 | 32.4 | 5.7 |
| 20 | 80 | do | 33.1 | 45.3 | 21.6 |
| 3 | 20 | Ammonium nitrate | 43.0 | 39.9 | 17.1 |
| 15 | 40 | do | 71.5 | 21.7 | 6.8 |
| 2 | 20 | Cyanamide | 26.0 | 33.3 | 40.7 |
| 16 | 40 | do | 25.4 | 42.2 | 32.4 |

It is evident that a very low nitrogen supply as represented by the control plots had a marked effect in delaying flowering. Addition of 10 pounds of nitrogen per acre had a decided effect in overcoming this delay, and an additional 10 pounds further hastened the reproductive process. Further increase in the nitrogen supply produced less significant results. On the whole, however, it appears that optimum conditions for flowering were supplied by 30 to 40 pounds of nitrogen per acre. The maximum rate of 80 pounds per acre seems to have slightly delayed flowering as compared with the 40-pound rate, at least in some cases.

As to the form of the nitrogen, cyanamide had a definite retarding action. When compared with the remaining sources nitrate of soda also tended to delay flowering.

Effects of the nitrogen supply on rate of development and subsequent decline of the leaf, more particularly as regards the lower leaves on the plant, were not entirely the same as those on time of flowering. Gain in weight per unit of area, that is, the accumulation of total dry matter which usually takes place during the ripening of the leaf, and the effects on these changes of the operation of topping or disbudding the plant, can be more satisfactorily dealt with in the section devoted to biochemical studies. Only changes in the general appearance of the leaves are considered here.

In general, the lower leaves reached full maturity earlier with the 20-pound rate of nitrogen fertilization than with the other treatments, and after a short time these leaves began to deteriorate and dry, a process popularly known as firing. Thus, with a relatively low content of nitrogen in the fertilizer there is a tendency for the lower leaves to

perish before the remaining leaves on the plant have attained full maturity. This tendency is less evident, however, where all nitrogen is omitted from the fertilizer. With the heavier rates of nitrogen fertilization there was little or no tendency toward firing in the lower leaves.

### COLOR OF LEAF

Where all nitrogen was omitted from the fertilizer the leaves of the plants showed a pale yellowish-green color throughout the season, which is perhaps the most distinctive symptom of nitrogen hunger. As the nitrogen supply was increased the leaves showed a progressively darker green color. Also, during the ripening period of the leaves, following topping, there was less tendency with heavy nitrogen fertilization for the leaves to gradually lose their dark-green color, as usually happens in normal ripening of the leaf. In the cured leaf, the color was comparatively dark when nitrogen was omitted from the fertilizer and there was a peculiar dullness or lack of luster. As a rule the lighter and brighter colors were obtained with 20 to 40 pounds of nitrogen per acre. With the 80-pound rate dark colors with a decided greenish cast were often obtained, especially in the earlier years of the tests, although in the later years this was not always the case.

As to the effects of the form of nitrogen on color of the green and cured leaf, no clearly defined differences were observed except in the case of ammonium chloride. At the lower rates of application of this material no decided abnormality in color was seen. With the 80-pound rate, however, the green leaf in the field showed a characteristic yellowish-green color having an oily appearance, and the cured leaf was almost black.

### BURNING QUALITIES OF LEAF

Samples of cured leaf of the 1925, 1927, and 1929 crops from the control plots and the nitrate of soda treatments, and from the 1925 and 1929 crop from the ammonium sulphate and ammonium chloride treatments were used for making the usual laboratory tests of fire-holding capacity of the leaf. As a hot point for igniting the leaf an electric cigar lighter was employed. On one half of each leaf the test was applied at four points near the margin and ranged from the tip to the base. The 1925 and 1927 samples were tested under ordinary laboratory conditions during the winter, that is, at a temperature of 70° to 75° F. and with a very low relative humidity. The 1929 samples were tested under accurately controlled conditions of temperature and humidity, namely, 77° and 54 percent relative humidity. The results are summarized in table 17.

TABLE 17.—*Effects of form and quantity of the nitrogen supplied in the fertilizer on the fire-holding capacity of the cured leaf in the years 1925, 1927, and 1929*

| Nitrogen applied in fertilizer | | Duration of glow | | |
|---|---|---|---|---|
| Quantity per acre (pounds) | Source | 1925 | 1927 | 1929 |
| | | *Seconds* | *Seconds* | *Seconds* |
| None | | 23 | 39.5 | 12.1 |
| 20 | Nitrate of soda | 9.6 | 14.6 | 3.1 |
| 40 | do | 11.8 | 8.1 | 3.2 |
| 80 | do | 10.6 | 4.6 | 2.7 |
| 20 | Ammonium sulphate | 13.5 | ---- | 5.0 |
| 40 | do | ---- | ---- | 3.9 |
| 80 | do | 13.5 | ---- | 3.8 |
| 20 | Ammonium chloride | ---- | ---- | 1.4 |
| 40 | do | ---- | ---- | 1.1 |
| 80 | do | 2.5 | ---- | .8 |

It is apparent that both the quantity and the form of nitrogen used in the fertilizer materially affected the fire-holding capacity or duration of glow of the leaf. It will be seen, moreover, that seasonal conditions in the different years greatly affected the results as a whole. It is well known that dry weather tends to reduce the fire-holding capacity and comparatively wet weather tends to produce the opposite effect. The best burn was obtained in 1927 when there was an abundant and fairly evenly distributed rainfall. Rather good results also were obtained in 1925 when July was wet and the August rainfall, though moderate, was very evenly distributed and adequate for rapid growth. The burn of the 1929 crop was very poor and far below the normal for Maryland tobacco, possibly as a result of light rainfall in August and the latter part of July. It is possible also that severe leaching of the soil by the very heavy rainfall of spring and early summer prior to transplanting was a factor in the poor results of 1929.

As regards the influence of the nitrogen supply, it is obvious that the first 20 pounds of nitrogen supplied in the fertilizer had a marked effect in reducing the combustibility of the tobacco. Additional quantities of nitrogen further lowered the capacity of the leaf to hold fire. It appears that the depressing effects of increasing quantities of nitrogen on combustibility were less consistently maintained in 1925 than in the other 2 years, but the reason for this is not known. As to sources of nitrogen, it seems that under the conditions of the fertilizer test ammonium sulphate produced a slightly better burn than nitrate of soda. It is likely that this result is correlated with the effect of ammonium sulphate in promoting rapid growth and development as indicated by relative time of flowering (table 16). As subsequently stated (p. 64), it is believed that the soil on which these tests were conducted is deficient in sulphur and this deficiency tends to delay the growth of the plant. Ammonium chloride as a source of nitrogen greatly impairs the burning qualities of the leaf. This effect is to be expected, perhaps, since it is well known that chlorine in the quantities here supplied in the ammonium chloride tends to seriously lower the fire-holding capacity of tobacco.

## INFLUENCE OF NITROGEN SUPPLY ON NUTRITION AND METABOLISM

### METHODS OF SAMPLING AND ANALYSIS

The chemical and physical characteristics of the individual leaf of the tobacco plant are profoundly affected by its relative position on the stalk and by its age. Hence, to obtain satisfactory comparison of the effects of different treatments it is essential that all leaf samples be chosen from the same position on the plant unless all of the leaves are taken. In the present case those from the lower half of the plant were generally used. The factor of age was controlled by making observations on a series of samples taken at intervals extending over a considerable period of development of the plant. In fixing the dates for collecting successive samples, account was usually taken of the date on which the first blossom appeared.

In the commercial culture of nearly all domestic types of tobacco it is the general practice to top the plants, that is, to break out the terminal portion of the stem, thus removing the flower bud together with some of the top leaves. However, the number of leaves removed in this way varies widely in the production of the different types of

tobacco, and there is also wide variation as to the stage of development at which the topping is done. In the experiments reported in the following paragraphs, except as otherwise stated, the plants were topped to the lowermost leafless sucker or lateral branch, and the topping was done when the first blossom opened. This sort of high and late topping approximates common practice in southern Maryland and in some of the other tobacco districts.

In sampling, as many plants as conditions would permit were utilized and, ordinarily, for each sample a single leaf or only one half of a leaf was taken from each plant. In studies on the cured product, with certain exceptions all the leaves on the plant were used. The fresh leaves were weighed as quickly as possible after harvest, and usually the outline of each leaf was traced on paper as a means of ascertaining the area. For some purposes the leaf material was at once frozen, macerated, ground, or otherwise prepared for immediate use. Where it was desired to preserve the leaves for later study they usually were plunged into boiling alcohol or exposed to chloroform vapor and then dried at about 60° C. or by a blast of dry air at room temperature. In certain cases, special methods of sampling and preparing the material were necessary, and these are mentioned in connection with the individual experiments. In some instances the whole leaf was used for study, while in others the midrib was removed and rejected.

It is desirable at this point to refer to the surprisingly large quantities of sand and fine earth that may adhere to the leaves of the tobacco plant, especially the lower leaves. It was found that in some cases this material accounted for a third of the total dry weight of the leaf. The largest relative weight of soil material adhering to the leaf was on the no-nitrogen plots where the plants were abnormally small. It was found desirable to apply the proper correction for the content of this soil material to many of the analytical data.

In preparation for analysis the air-dried leaf material was ground to pass a 40-mesh sieve and preserved in tightly stoppered jars. The stalks were first passed through a high-speed hammer mill of the type used in grinding cattle feeds, in preparation for the final grinding in a Wiley mill.

In the analytical work the following methods were employed unless otherwise stated:

*Moisture.*—The procedure, used chiefly, was to dry for 4 hours at 100° C. An alternative method consisted in drying to constant weight over concentrated sulphuric acid.

*Total nitrogen.*—The official Gunning method modified to include nitrates as applied to fertilizers (*3, p. 21*), but with addition of 0.7 g of mercuric oxide, was employed. Thorough digestion of the acid mix is necessary to insure complete decomposition of nicotine and related bodies.

*Protein nitrogen.*—The tobacco powder (2 g) was boiled 5 minutes with 0.5 percent acetic acid and the mixture was filtered when cold. The residue was washed with hot 0.5 percent acetic acid until the filtrate was colorless. The nitrogen in the residue was determined by the official Kjeldahl-Gunning-Arnold method (*3, p. 21*). In some cases, however, the official (Stutzer) method for albuminoid nitrogen in grain and stock feeds (*3, p. 279*), which gives slightly higher figures, was followed. The nitrogen value found was multiplied by the factor 6.25 to obtain the protein figure.

*Nicotine.*—A modification of the Keller method developed in the Division of Tobacco and Plant Nutrition was chiefly employed. Six grams of tobacco in a ½-pint E-Z seal type of preserve jar was thoroughly mixed with 5 cc of 7.5 percent aqueous caustic soda by means of a spatula. One hundred cubic centimeters of gasoline was added from a pipette, the jar being covered with a thin block of wood

properly notched to receive the stem of the pipette. The jar was sealed with a rubber ring and glass cover, rotated to mix the contents and allowed to stand overnight. After thoroughly mixing the extract, the tobacco was caused to collect on one side by tapping the edge of the jar, which was maintained in an inclined position for an hour or longer to allow the extract to clarify. Fifty cubic centimeters of the extract was withdrawn by means of a pipette the end of which was fitted with a filter tube. This tube was a glass cylinder about 2 inches long and 1⅛ inches in diameter, over one end of which was placed a filter paper held in place with a rubber ring. The open end was connected with the pipette by means of a one-hole rubber stopper. With the wooden cover in place on the jar, the extract was drawn through the filter into the pipette and placed in a dry 200-cc Erlenmeyer flask. While standing uncovered for an hour the flask was gently rotated several times to cause all ammonia to escape. Exactly 10 or 15 cc of 0.1 N sulphuric acid and 50 cc of water containing the indicator (methyl red or cochineal) were added. The contents were thoroughly mixed and allowed to stand until the two layers had sharply separated. Fifty cubic centimeters of the aqueous layer was withdrawn with a pipette and titrated with 0.1 N alkali. One cubic centimeter 0.1 N sulphuric acid is equivalent to 0.01621 g of nicotine. In certain instances the official silicotungstic-acid procedure (*3, p. 55*) was followed.

*Ammonia.*—Twelve grams of the tobacco sample were boiled 5 minutes with 150 cc of 0.5 percent acetic acid under a reflux condenser. After cooling, the extract was passed through paper pulp on a Buchner funnel, using suction. The residue was washed with hot 0.5 percent acetic acid till the filtrate was colorless. The filtrate was transferred to a 300-cc flask, sufficient 12 percent hydrochloric acid was added to form a 0.3 percent solution and sufficient 12 percent silicotungstic acid solution to precipitate all of the nicotine. After the mixture had stood overnight the flask was filled to the mark with water and the contents filtered. A 250-cc aliquot of the filtrate corresponding to 10 g of tobacco was used for determination of ammonia, amide, amino, and nitrate nitrogen. For determination of ammonia an apparatus train was used consisting of: (1) A flask containing dilute sulphuric acid; (2) a similar flask containing ammonia-free water; (3) a Kjeldahl flask containing the test solution; (4) a small guard flask; (5) a liter flask containing 30 cc of 0.2 N sulphuric acid diluted with ammonia-free water and connected with an absorption tower containing bits of small glass tubing; and (6) a guard flask leading to the suction. An open-end manometer filled with glycerol connected with the apparatus immediately beyond the absorption tower aids in maintaining a steady rate of aeration. To facilitate the scrubbing action of the air current the lower ends of the inlet tubes of flasks 1, 2, and 3 are provided with bulbs containing several small openings. The test solution was made nearly neutral with sodium hydroxide and a few drops of kerosene added to prevent frothing, after which 2 cc of saturated potassium oxalate solution and 3 cc of saturated potassium carbonate solution also were added. A current of air was drawn through the apparatus for 3 hours at the rate of 500 l per hour and the residual acid in the absorption flask and tower was titrated with 0.2 N sodium hydroxide, using methyl red as indicator.

*Amide nitrogen.*—The residual extract from the ammonia determination is neutralized and evaporated to 100 cc, after which sufficient sulphuric acid is added to produce a 5 percent solution. The mixture is boiled 2 hours under a reflux condenser. After cooling and diluting, a little paraffin, a few pieces of pumice, and sufficient caustic soda to give an approximately 0.1 N solution are added. One hundred cubic centimeters are distilled into an excess of 0.05 N sulphuric acid and the ammonia determined by titration.

*Amino nitrogen.*—The tentative official Van Slyke method for meats and meat products (*3, p. 297*) was used. An aliquot of the residual solution from determination of amide nitrogen corresponding to 2 g of tobacco was made slightly acid to litmus with acetic acid and evaporated to a small volume. This was made up to 20 cc and 10 cc of the solution, corresponding to 1 g of tobacco, was used for the determination.

*Nitrate nitrogen.*—To an aliquot of the residual solution from determination of amide corresponding to 8 g of tobacco adjusted to 0.1 N Caustic Soda 2 g of Devarda alloy powder were added. The mixture was distilled and the distillate collected in an excess of sulphuric acid. The ammonia thus obtained represents the nitrate present. To check against possible mechanical transfer of alkali to the distillate this was redistilled into 0.1 N sulphuric acid after adding magnesia free from carbonate.

*Starch.*—The official method for starch in the presence of interfering polysaccharides as applied to grain and stock feeds (*3, p. 282*) was employed in the

analyses presented in table 26. In other cases the alcohol treatment for precipitation of pectins or gums was omitted. It is believed that any errors resulting from this omission were small and of little significance for comparative purposes.

*Sugars.*—The official methods for reducing sugars and sucrose in grain and stock feeds (*3, p. 281*) were used. For preparation of the solution 5 to 10 g of the tobacco were employed. In clarifying the extract, addition of neutral lead acetate was continued till no further precipitate was formed. In samples of uncured leaf some trouble was experienced from yellowish, flaky copper precipitates which were rather difficult to filter. The reduced copper was weighed as cupric oxide after heating the precipitate to red heat in a muffle furnace.

*Fiber.*—As a rough measure of cellulose content the official method for crude fiber in grain and stock feeds (*3, p. 280*) was employed.

*Pectic constituents.*—The procedures of Conrad (*7*) and Appleman and Conrad (*2*) as applied to tomatoes and based on the methods of Carré and of Carré and Haynes were used to obtain the approximate content of pectin, protopectin, and pectic acid. The tobacco (2.5 g) was washed on a filter with water till the filtrate was free of pectin. Soluble pectin if present was determined in the filtrate in accordance with the procedure of Appleman and Conrad. The tobacco residue was washed with alcohol, dried at 70° C., boiled 30 minutes with N/30 hydrochloric acid, neutralized with caustic soda, and boiled 30 minutes with sufficient ammonium citrate to give a 1 percent solution. After cooling, the solution was diluted to a volume of 250 cc and filtered. The pectic acid was determined as calcium pectate in an aliquot (20 cc), following the procedure of Appleman and Conrad. In a second aliquot of 20 cc the combined protopectin and pectic acid were determined as calcium pectate by successive treatment with sodium hydroxide, acetic acid, and calcium chloride, as outlined by Conrad. The nitrogen content of the calcium pectate precipitates was found to be too low to justify attempts to further purify these precipitates. This may be accomplished when required, however, by redissolving in boiling ammonium citrate and applying a correction for any undissolved residue.

*Nonvolatile organic acids.*—Malic, citric, and oxalic acids have been generally regarded as the most important nonvolatile organic acids in leaf tobacco. Unfortunately, there is no entirely satisfactory method available for the quantitative separation of these acids in tobacco. Vickery and Pucher (*27*) have recently pointed out that in the Kissling method (*15*), which has been used to a considerable extent in the analysis of tobacco leaf, there can be no assurance that the precipitates obtained represent pure salts of malic, citric, and oxalic acids. This criticism has special significance perhaps with respect to malic and citric acids. However, Piatnitzki (*20*) considers that the Kissling method is of value for purely comparative purposes. This investigator believes that with certain modifications the method yields accurate results for oxalic acid and fairly satisfactory results for malic acid, while the values for citric acid are distinctly low. He recommends that citric acid be extracted by the Kissling method and determined by conversion into pentabromacetone.

In obtaining the data presented in table 35 the acids were first obtained in ether extracts both by the Kissling procedure and by first extracting the tobacco with 2 N sulphuric acid and then exhausting this extract with ether, according to the method used by Vickery and Pucher in extracting and recovering the oxalic acid in their material. For the latter extraction with ether the Palkin automatic extraction apparatus was used. The citric acid was determined by conversion into pentabromacetone according to the official method for citric acid in fruits and fruit products (*3, p. 273*). The oxalic acid was precipitated as the calcium salt in the dilute solution moderately acidified with acetic acid. The calcium salt was dried and weighed as such, after which it was dissolved in dilute sulphuric acid and titrated with potassium permanganate. The citric and oxalic acid values obtained by the two methods of extraction showed fairly good agreement, and there was excellent agreement in the oxalic acid values obtained gravimetrically and by titration with permanganate. The data for citric and oxalic acids in the uncured leaf presented in table 24 were obtained by the Kissling method before the work of Vickery and Pucher appeared and, unfortunately, material was not available for checking these data by the revised procedure. The values for malic acid in tables 24 and 35 were obtained by the Kissling method, and it is recognized that the fractions thus designated may have contained small quantities of impurities. It has been the experience of the writers that in applying the Kissling method of extracting the acids from tobacco it is often necessary to increase by 25 percent the quantity of sulphuric acid recommended by Kissling to insure complete liberation of oxalic acid in the product.

*Tobacco resins.*—The empirical procedure of Degrazia (*8*) was applied to the cured leaf, using however only 10 g of material for extraction. It was found extremely difficult to obtain quantitative extraction of the resene fraction with ether after saponification of the extract with alkali, so that the values for resene probably are only approximately correct.

*Ash constituents.*—For total ash 5 to 10 g of material were ignited to a dull red in a muffle furnace till the residue was white or nearly so. The several constituents of the ash were determined in accordance with the official methods for plants (*3, p. 102*).

### RECOVERY OF FERTILIZER NITROGEN BY THE CROP AND ITS DISTRIBUTION IN THE LEAF AND STALK

In 1919, 1925, and 1929 representative samples of the cured leaf and stalk from the plots receiving nitrogen at the rates of 20, 40, and 80 pounds per acre in the form of nitrate of soda and from the control plots were analyzed to ascertain the relative quantities of nitrogen recovered by the crop when the nitrogen supply of the soil was increased. The results are presented in table 18. In this table all analytical data are calculated to a uniform moisture content of 15 percent, which is approximately the moisture content of Maryland leaf tobacco when in proper condition for handling. The observed plot yields were used as a basis for computing the quantity of nitrogen recovered by the crop.

TABLE 18.—*Recovery by the tobacco crop of fertilizer nitrogen applied at various rates in 1919, 1925, and 1929*

PERCENTAGE OF NITROGEN IN THE PLANT

| Quantity of nitrogen in fertilizer, per acre (pounds) | 1919 | | | 1925 | | | 1929 | | | 3-year average | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Leaf | Stalk | Whole plant | Leaf | Stalk | Whole plant | Leaf | Stalk | Whole plant | Leaf | Stalk | Whole plant |
| 0 | 1.40 | 1.58 | ..... | 1.03 | 1.55 | ..... | 1.36 | 1.68 | ..... | 1.27 | 1.60 | ..... |
| 20 | 1.61 | 1.69 | ..... | 1.36 | 1.62 | ..... | 1.60 | 1.91 | ..... | 1.52 | 1.74 | ..... |
| 40 | 1.58 | 1.66 | ..... | 1.56 | 1.84 | ..... | 1.87 | 1.90 | ..... | 1.67 | 1.80 | ..... |
| 80 | 1.83 | 1.81 | ..... | 2.07 | 2.35 | ..... | 2.06 | 2.06 | ..... | 1.99 | 2.07 | ..... |

QUANTITY OF NITROGEN CONTAINED IN THE CROP (POUNDS PER ACRE)

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 7.9 | 6.0 | 13.9 | 8.6 | 6.3 | 14.9 | 11.0 | 5.6 | 16.6 | 9.2 | 6.0 | 15.2 |
| 20 | 11.2 | 10.6 | 21.8 | 15.3 | 12.0 | 27.3 | 21.1 | 13.6 | 34.7 | 15.9 | 12.1 | 28.0 |
| 40 | 12.5 | 11.7 | 24.2 | 19.1 | 14.5 | 33.6 | 23.2 | 14.1 | 37.3 | 18.3 | 13.4 | 31.7 |
| 80 | 15.9 | 12.2 | 28.1 | 26.1 | 20.9 | 47.0 | 30.7 | 16.5 | 47.2 | 24.2 | 16.6 | 40.8 |

Of the first 20 pounds of nitrogen applied in the fertilizer the crop recovered in round numbers 40, 60, and 90 percent, respectively, in the years 1919, 1925, and 1929, the 3-year average being 64 percent. The apparently abnormally high recovery in 1929 is coupled with an exceptionally high crop yield on the particular plot involved, the reason for which is not known. If the 1929 value is disregarded, the indicated recovery of the first 20 pounds of fertilizer nitrogen amounts to 40 to 60 percent of the total applied to the soil. The additional quantity of nitrogen recovered by the crop when 40 pounds of nitrogen was applied is small, the average for the 3 years amounting to less than 4 pounds or 20 percent of the second 20 pounds of nitrogen included in the fertilizer. The recovery was comparatively small in each of the 3 years, possibly due in part to some soil

condition on this plot which was unfavorable for absorption of the additional fertilizer nitrogen. It is worthy of mention, however, that nitrogen recovery in this treatment as compared with the 20-pound rate of fertilization was distinctly better in 1925 than in the other 2 years. Of the 40 pounds supplied in the fertilizer in this treatment, the quantity contained in the crop in excess of that absorbed by the crop in the no-nitrogen treatment averaged for the 3 years 16.5 pounds, or 41 percent of the quantity applied. The nitrogen recovery in the 80-pound rate of fertilization was approximately 18 percent in 1919, 40 percent in 1925, and 38 percent in 1929.

There is a definite though not a uniform increase in the percentage content of nitrogen in both leaf and stalk as the quantity of nitrogen in the fertilizer is increased. Usually this increase is more marked in the leaf, however, than in the stalk. The greatest increase in percentage content of nitrogen, at least in the leaf, results from the first 20 pounds of nitrogen supplied in the fertilizer, even though much the largest increase in yield of both leaf and stalk also is produced by this first 20 pounds of fertilizer nitrogen. The percentage of nitrogen in the stalk usually exceeds somewhat that of the leaf, especially when the supply of nitrogen in the soil or fertilizer is low.

The actual quantity of nitrogen contained in the leaf exceeds that in the stalk in all cases, but the amount of the excess varies considerably from year to year. The greatest difference in nitrogen content of leaf and stalk is found in the 1929 crop because of the unusually high yield of leaf in comparison with the yield of stalk. On an average, about 60 percent of the nitrogen is found in the leaf and 40 percent in the stalk with both light and heavy rates of nitrogen fertilization. A striking feature of the results for the control plots is that in 1929, after 10 years of continuous cropping without addition of any nitrogen in the fertilizer, the quantity recovered by the crop exceeds that recovered in the first year of the experiment. For the 3 years in which observations were made the average quantity of nitrogen in the crop from the control plots amounted to about one third of the quantity in the crop most heavily fertilized with nitrogen.

The leaf material obtained from selected plants in 1929 for study of weight of cured leaf per unit area (p. 28), and the corresponding stalks also were employed in observations on the distribution of nitrogen in the midrib and the lamina of upper, middle, and lower leaves, and in the stalk, as affected by increase in the supply of fertilizer nitrogen. In addition to these individual leaves from the upper, middle, and lower portions of the plant, which were used to obtain data on the nitrogen content of the lamina and the midrib, all the remaining leaves from the three parts of the plant were employed for ascertaining the nitrogen content of the entire leaves in order to insure better average values. The lowermost or ground leaves which had partially dried at time of harvest also were collected separately and analyzed. These ground leaves are often collected, cured, and marketed by growers in southern Maryland. The analytical data are summarized in table 19.

TABLE 19.—*Content of nitrogen in the lamina and midrib of upper, middle, and lower leaves, in the leaves as a whole, and in the stalk, as affected by the quantity of nitrogen applied in the fertilizer, season of 1929*

| Quantity of nitrogen applied per acre (pounds) | Position of leaf on stalk | Percentage of nitrogen in— | | | | Milligrams of nitrogen per square foot of leaf |
|---|---|---|---|---|---|---|
| | | Leaf | | Whole leaf | Stalk | |
| | | Lamina | Midrib | | | |
| None | Upper | 2.34 | 1.40 | 2.13 | | 114.1 |
| | Middle | 1.94 | .92 | 1.68 | | 93.5 |
| | Lower | 1.67 | .68 | 1.40 | | 99.1 |
| | Ground | | | .39 | | |
| | All leaves | | | 1.47 | | |
| 20 | Upper | 2.65 | 2.23 | 2.45 | | 141.2 |
| | Middle | 2.13 | 1.26 | 1.92 | | 90.6 |
| | Lower | 1.79 | .78 | 1.60 | | 91.2 |
| | Ground | | | .48 | | |
| | All leaves | | | 1.76 | 2.01 | |
| 40 | Upper | 3.81 | 2.18 | 3.22 | | 166.8 |
| | Middle | 2.67 | 1.66 | 2.46 | | 104.1 |
| | Lower | 1.97 | 1.02 | 1.80 | | 101.1 |
| | Ground | | | .60 | | |
| | All leaves | | | 2.24 | 2.42 | |

Considering the results as a whole, the percentage content of nitrogen in the midrib averages slightly more than one half that in the lamina or web of the leaf and is lower than that of the stalk. In comparison with the lamina the midrib contains relatively least nitrogen in the lower leaf and most in the upper leaf, especially when the soil supply of nitrogen is low. The actual percentage of nitrogen in both midrib and lamina is highest in the upper and lowest in the lower leaves. In the lower and middle leaves and to a lesser extent in the upper leaves the effect of an increased supply of fertilizer nitrogen is to increase the nitrogen content of the midrib, and this applies generally also to the lamina. Taking the leaf as a whole, there is a well-defined increase in nitrogen from the ground leaf to the upper leaf, the former being rather low in this element. However, there is little difference in nitrogen content per unit area between the lower and the middle leaves. The greatest effect of an increased supply of nitrogen in the fertilizer in increasing the nitrogen content of the leaf on a percentage basis or on a basis of equal area is in the upper leaves of the plant. As in table 18, the percentage of nitrogen is somewhat higher in the stalk than in the leaf. The distribution of total nitrogen between stalk and leaf and between the web and midrib of the leaves is of interest chiefly as indicating the fertilizing value of the stalk and leaf midrib as sources of nitrogen.

### MINIMUM NITROGEN REQUIREMENTS

The data in table 18 illustrate the fact that the minimum content of nitrogen in the leaf which will suffice to prevent visible symptoms of nitrogen hunger varies considerably with change in environmental conditions. An abnormally pale or yellowish-green color of the leaves which is the most characteristic symptom of nitrogen hunger in the plant was always evident on the control plots but scarcely could be recognized on the plots receiving 20 pounds of fertilizer nitrogen. Nevertheless, the leaf crop grown on the latter plots in

1925 contained about the same percentage of nitrogen as the leaf grown on the control plots in 1919 and 1929. However, it appears that symptoms of nitrogen hunger are likely to be seen when the nitrogen supply is such that the content of the cured leaf falls below about 1.5 percent. The plant was able to make most effective use of the nitrogen actually absorbed in the crop season of 1925. Disregarding the small quantity of nitrogen in the roots, in that year each pound of nitrogen absorbed by the plant produced 56, 41, 36, and 27 pounds of cured leaf, respectively, on the control plots and those receiving 20, 40, and 80 pounds of nitrogen in the fertilizer.

### WATER RELATIONS IN THE PLANT

In 1929 a series of leaf samples covering the growing period up to the flowering stage was taken from the plots of the primary series receiving nitrogen from nitrate of soda at the rates of 0, 20, 40, and 80 pounds per acre. For this purpose three groups of 20 uniform plants each were selected, the successive samples being taken from the three groups in regular rotation. Samples were taken 47, 40, 32, 25, 17, and 11 days, respectively, before flowering and at time of first flowering. For the first sample in each group the fifth leaf from the bottom was used, and for each succeeding sample the next higher leaf was used. At the flowering stage, samples were taken from both the first and the second groups of plants. For each sample only a half of each leaf was collected by cutting the leaf lamina along the midrib, the remainder of the leaf being left attached to the plant. This method of sampling was followed in order to reduce to a minimum any disturbance in the normal processes of plant activity. After obtaining the fresh weight, the area of the leaf material was ascertained by tracing the outlines of each half leaf on paper. The material was then exposed to chloroform vapor to induce plasmolysis and quickly dried at air temperature in a current of air dried over strong sulphuric acid. In ascertaining the true fresh and dry weights, a correction for adhering earthy material, as determined in the ash, was applied. The water content of the several samples is shown in table 20.

TABLE 20.—*Effect of increasing the nitrogen supply in the fertilizer on the total area of the lower leaves of the plant, their water content and dry weight per square foot, and the content of total, protein, nitrate, nicotine, ammonia, amino, and amide and residual nitrogen in the leaves through a period of 47 days extending up to the time of first flowering, season of 1929*

| Number of days before flowering | Quantity of nitrogen in fertilizer, per acre | Average area of 10 leaves | Water content of leaf | Weight of dry matter per square foot | Nitrogen in 1 square foot of leaf as— | | | | | | | | Nitrogen in 1 leaf as— | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total nitrogen | Protein nitrogen | Nitrate nitrogen | Nicotine nitrogen | Ammonia nitrogen | Amino nitrogen | Amide nitrogen | Residual nitrogen | Total nitrogen | Protein nitrogen |
| | *Pounds* | *Sq. ft.* | *Per-cent* | *Gms.* | *Milli-grams* | *Milli-grams* | *Milli-grams* | *Milli-grams* | *Milli-grams* | *Milli-grams* | *Milli-grams* | *Milli-grams* | *Milli-grams* | *Milli-grams* |
| 47 | None | 5.696 | 83.71 | 4.209 | 142.0 | 115.6 | 0.2 | ------ | 0.4 | 5.5 | 0.9 | ------ | 80.9 | 66.1 |
| | 20 | 5.465 | 84.32 | 4.012 | 163.8 | 130.8 | .9 | ------ | .7 | 4.9 | 1.3 | ------ | 89.7 | 71.7 |
| | 40 | 5.246 | 85.40 | 3.918 | 169.5 | 131.4 | 2.3 | ------ | .8 | 4.7 | 1.6 | ------ | 89.3 | 68.8 |
| | 80 | 7.438 | 85.45 | 4.109 | 178.1 | 137.5 | 3.7 | 13.3 | .9 | 4.9 | 1.9 | 15.9 | 132.4 | 102.7 |
| 40 | None | 5.840 | 84.06 | 4.341 | 127.5 | 93.2 | .1 | 14.0 | .3 | 5.5 | 1.1 | 13.3 | 74.8 | 54.3 |
| | 20 | 6.570 | 85.84 | 3.957 | 164.1 | 117.9 | 1.5 | 18.0 | .7 | 7.3 | 1.6 | 17.1 | 107.7 | 77.5 |
| | 40 | 6.358 | 84.68 | 4.311 | 161.1 | 114.3 | 1.4 | 17.0 | .6 | 6.9 | 1.7 | 19.2 | 102.7 | 72.7 |
| | 80 | 7.820 | 85.83 | 4.082 | 149.0 | 110.1 | 1.5 | 15.5 | .6 | 6.9 | 1.4 | 13.0 | 116.5 | 86.0 |
| 32 | None | 5.851 | 83.08 | 5.098 | 126.4 | 83.5 | .3 | 18.3 | .5 | 6.5 | 1.1 | 16.2 | 73.7 | 49.1 |
| | 20 | 6.500 | 83.02 | 4.720 | 159.0 | 103.6 | .8 | 24.3 | .8 | 8.4 | 1.4 | 19.7 | 103.4 | 67.6 |
| | 40 | 6.734 | 84.28 | 4.395 | 166.0 | 105.9 | 1.6 | ------ | .7 | 7.2 | 1.6 | ------ | 111.7 | 71.3 |
| | 80 | 8.270 | 85.84 | 4.090 | 142.3 | 93.6 | 1.4 | 21.2 | .6 | 7.1 | 1.3 | 17.1 | 117.4 | 77.7 |
| 25 | None | 6.324 | 83.84 | 4.405 | 109.6 | 66.9 | .03 | 18.1 | .4 | 6.2 | 1.0 | 17.0 | 69.5 | 42.3 |
| | 20 | 6.637 | 84.88 | 4.236 | 137.8 | 89.0 | .7 | 22.5 | .6 | 8.0 | 1.3 | 15.7 | 91.6 | 59.1 |
| | 40 | 6.710 | 85.36 | 4.106 | 135.8 | 81.7 | 1.1 | 23.2 | .6 | 7.4 | 1.4 | 20.4 | 91.3 | 55.0 |
| | 80 | 8.867 | 85.67 | 4.210 | 141.5 | 88.1 | 1.6 | 21.9 | .6 | 7.5 | 1.4 | 20.4 | 126.0 | 78.1 |
| 17 | None | 6.882 | 83.78 | 4.331 | 88.4 | 50.9 | .06 | 14.7 | .4 | 3.4 | .8 | 18.1 | 60.5 | 35.1 |
| | 20 | 7.734 | 84.44 | 4.347 | 104.6 | 61.2 | .2 | 20.5 | .4 | 4.5 | .9 | 16.9 | 81.2 | 47.2 |
| | 40 | 7.591 | 85.53 | 4.189 | 120.9 | 72.6 | .3 | 21.8 | .4 | 5.1 | 1.1 | 19.6 | 91.8 | 55.4 |
| | 80 | 9.071 | 86.40 | 3.893 | 116.2 | 70.0 | .4 | 19.9 | .4 | 5.1 | 1.2 | 19.2 | 105.2 | 63.5 |
| 11 | None | 7.633 | 82.45 | 4.610 | 89.5 | 51.8 | .0 | 15.2 | .4 | 3.6 | 1.0 | 17.5 | 68.7 | 39.7 |
| | 20 | 7.754 | 82.42 | 4.992 | 124.5 | 71.4 | .06 | 24.8 | .5 | 5.8 | 1.3 | 20.6 | 96.9 | 55.0 |
| | 40 | 7.465 | 83.86 | 4.417 | 115.1 | 67.0 | .2 | 21.7 | .4 | 5.1 | 1.2 | 19.5 | 85.9 | 50.0 |
| | 80 | 9.812 | 85.35 | 4.158 | 114.0 | 68.0 | .5 | 21.2 | .4 | 5.1 | 1.2 | 17.6 | 111.8 | 66.7 |
| At flowering | None | 7.201 | 83.60 | 4.533 | 88.4 | 48.2 | .3 | 15.8 | .5 | 4.4 | 1.1 | 18.1 | 63.4 | 34.6 |
| | 20 | 8.136 | 84.51 | 4.217 | 94.0 | 51.2 | .3 | 18.3 | .5 | 4.8 | 1.0 | 17.9 | 76.5 | 41.5 |
| | 40 | 7.963 | 85.37 | 4.154 | 100.8 | 54.4 | .4 | 20.9 | .3 | 5.0 | 1.0 | 18.8 | 80.4 | 43.0 |
| | 80 | 10.661 | 85.78 | 4.138 | 116.7 | 63.9 | .6 | 22.8 | .5 | 7.1 | 1.4 | 20.4 | 124.7 | 68.2 |
| Do | None | 7.556 | 83.80 | 4.336 | 82.1 | 44.8 | .3 | 12.4 | .4 | 4.5 | .9 | 18.8 | 62.0 | 34.0 |
| | 20 | 9.283 | 84.06 | 4.386 | 92.9 | 51.7 | .3 | 17.2 | .5 | 4.9 | .9 | 17.4 | 86.3 | 48.3 |
| | 40 | 9.192 | 86.09 | 3.794 | 96.3 | 51.6 | .4 | 20.2 | .6 | 5.3 | 1.0 | 17.2 | 88.2 | 47.8 |
| | 80 | 10.125 | 85.96 | 3.794 | 102.7 | 58.9 | .4 | 18.3 | .6 | 5.8 | 1.0 | 17.7 | 104.3 | 59.8 |

The results show a clearly defined trend toward increased water content with increase in the nitrogen supply. These results have been verified repeatedly in other years and there can be no doubt that the relationship applies generally. It is evident that an increased supply of nitrogen enables the plant the better to withstand excessive transpiration losses and resultant loss of turgidity. In popular language, the plants are more sappy. It is interesting to note that the effect of an increased nitrogen supply on the water content of the leaf is associated with definite effects on the physical characteristics of the leaf (table 20).

A series of observations was made in 1924 on the comparative effects of nitrate of soda, ammonium sulphate, and ammonium chloride on the water content of the green leaf tissue when applied at rates to supply 80 pounds of nitrogen per acre. The results along with those from certain other treatments have been published elsewhere (*10*). It will be sufficient to point out here that ammonium chloride was distinctly more effective in maintaining a high water content in the leaf than the other forms, an effect believed to be due to the properties of the chloride ion. Apparently the ammonium sulphate was the least effective in this particular of the three forms used, but

the reason for this is not apparent. In some of the treatments studied in 1924 there seemed to be a decrease in water content with increasing age of the leaf, but a similar change was not observed with the heavier rates of nitrogen fertilization.

To ascertain the effect of an increased nitrogen supply in the fertilizer on the hygroscopic properties of the dried leaf material, samples were allowed to come into equilibrium with various fixed vapor pressures or relative humidities. These humidities were obtained by use of saturated salt solutions in closed containers at a fixed temperature of 83° F. The salts employed were ammonium nitrate, sodium nitrate, ammonium sulphate, and potassium chloride, and these supplied relative humidities of approximately 61.4 percent, 74.5 percent, 80.2 percent, and 85.3 percent, respectively. To ascertain the moisture content of the samples at these humidities they were dried at 100° C. for 4 hours. The three series of 1925 leaf samples used for study of nonvolatile organic acids and prepared as described on page 45 were utilized for the present study, and, in addition, the 1925 samples of cured leaves described on page 59 and a 1929 series of samples of cured leaves from the same plots were employed. To obtain direct evidence as to the effect of the curing process on the hygroscopic properties of the leaf, tests were made with representative mature leaves taken from a plot receiving 80 pounds of nitrogen per acre derived from ammonium sulphate. One half of each leaf was exposed to chloroform vapor and quickly dried while the remaining half of each leaf was cured normally. The results of the observations with the several lots of dried leaf material are shown in table 21.

TABLE 21.—*Effect of increasing the nitrogen supply in the fertilizer on the hygroscopic properties of the dried leaves of the plant, before and after curing, 1925 and 1929*

| Year, number of picking, and character of sample | Quantity of nitrogen in the fertilizer, per acre | Water content of tobacco | | | |
|---|---|---|---|---|---|
| | | Over $NH_4NO_3$ solution, relative humidity 61.4 | Over $NaNO_3$ solution, relative humidity 74.5 | Over $(NH_4)_2SO_4$ solution, relative humidity 80.2 | Over KCl solution, relative humidity 85.3 |
| 1925: | *Pounds* | *Percent* | *Percent* | *Percent* | *Percent* |
| First picking, uncured | 0 | 10.87 | 14.55 | 16.80 | 18.60 |
| | 20 | 11.03 | 14.63 | 18.14 | 19.93 |
| | 40 | 10.68 | 14.62 | 17.91 | 19.73 |
| | 80 | 10.79 | 14.78 | 18.96 | 21.03 |
| Second picking, uncured | 0 | 10.62 | 14.12 | 16.65 | 18.24 |
| | 20 | 10.52 | 14.06 | 17.18 | 18.92 |
| | 40 | 10.01 | 14.06 | 17.40 | 19.03 |
| | 80 | 10.17 | 14.42 | 17.90 | 20.55 |
| Third picking, uncured | 0 | 10.39 | 13.55 | 16.30 | 18.31 |
| | 20 | 10.48 | 13.64 | 16.63 | 18.81 |
| | 40 | 9.79 | 14.11 | 17.25 | 18.95 |
| | 80 | 10.38 | 14.67 | 18.28 | 19.96 |
| All leaves on plant, cured | 0 | 7.19 | 9.90 | 12.46 | 13.71 |
| | 20 | 8.67 | 11.82 | 13.59 | 15.29 |
| | 40 | 8.80 | 12.35 | 15.02 | 17.30 |
| | 80 | 9.49 | 13.29 | 15.81 | 18.04 |
| 1929: | | | | | |
| Lower leaves, cured | 0 | 10.04 | 14.11 | 18.29 | 21.08 |
| | 20 | 11.60 | 15.14 | 19.07 | 21.69 |
| | 40 | 11.01 | 15.17 | 19.21 | 21.29 |
| | 80 | 11.59 | 16.38 | 19.76 | 23.38 |
| Do | 80 | 12.24 | 17.63 | ---------- | 27.11 |
| Lower leaves, uncured | 80 | 10.77 | 14.13 | ---------- | 18.93 |

The results obtained with the 1925 uncured material show that, as a whole, there is a well-defined tendency toward decreased affinity for water with increasing age of the leaf, although this tendency is less marked with the highest rate of nitrogen fertilization. Except at the lower relative humidities, there is definite increase in affinity for water as the rate of nitrogen fertilization is increased. This effect of an increased nitrogen supply is especially marked in the 1925 and 1929 cured material. The comparison of 1929 cured and uncured leaf shows a decided increase in affinity for water as a result of the curing.

### OSMOTIC CONCENTRATION OF CELL SAP

A few observations were made on the osmotic concentration of the cell sap of the leaf during the later stages of development and the ripening process, as affected by the nitrogen supply. In 1926, leaf samples were taken at intervals from the same field plots that were used in 1929 for the preceding studies on water relations in the plant. Each sample was taken from 12 selected plants, one leaf being chosen from each plant. All samples were collected between 10 and 11 a.m. For the first observations the leaf attached to the middle portion of the stalk was used, and for each of the later samples the leaf immediately above the one taken for the preceding sample was employed. One half of each leaf was cut off along the midrib and this was again halved crosswise, using the frontal or distal portion for the sample. The leaf material was frozen and the sap expressed at a fixed pressure. The specific lowering of the freezing point of the expressed sap was determined, and the equivalent osmotic concentration was calculated in the usual manner. The results are given in table 22.

TABLE 22.—*Effect of quantity and form of the nitrogen supply on the osmotic concentration of the cell sap of tobacco leaves in the later stages of growth and during the ripening process, season of 1926*

| Nitrogen applied in fertilizer | | Osmotic concentration of cell sap in atmospheres— | | | | |
|---|---|---|---|---|---|---|
| Quantity per acre (pounds) | Form | 15 days before flowering | At time of flowering | 8 days after flowering | 15 days after flowering | 16 days after flowering |
| None | | | 8.793 | 8.071 | | 9.394 |
| 20 | Nitrate of soda | | 8.552 | 8.071 | | 9.154 |
| 40 | do | | 7.830 | 7.469 | | 9.093 |
| 80 | do | | 8.071 | 7.590 | | 9.755 |
| 80 | do | 8.312 | 8.432 | | 9.033 | |
| 80 | Ammonium sulphate | 8.191 | 7.590 | | 8.131 | |
| 80 | Ammonium chloride | 10.240 | 8.732 | | 9.514 | |

These data show no clearly defined relationship between the quantity of nitrogen supplied the plant and the osmotic concentration of the cell sap of the leaf, although, on the whole, the tendency is toward a reduced osmotic value with an increase in the nitrogen supply except toward the end of the period of observation. As regards the effects of different forms of nitrogen, the ammonium chloride produces the highest osmotic values while ammonium sulphate gives the lowest values. These relationships are similar to those observed in the studies of relative water content of the leaf. On the other hand, the increased water content of the leaf resulting from an increase in the

quantity of nitrogen supplied the plant is not accompanied by an increase in osmotic concentration of the cell sap.

### ACIDITY RELATIONS

In 1919 a series of observations were made on the pH value of the sap of leaves taken from the primary series of field plots, beginning at time of topping, which was also the time of first flowering. Six selected plants were used for each sample, and on each plant one half of the middle leaf, cut off along the midrib, was taken for the first sample. Each succeeding sample was taken from the next higher leaf on the plant. The samples were collected September 5, 10, 15, 20, 25, and October 4, 9, 14, and 18. A second series of samples was taken from the same plants, proceeding downward from the middle leaf in procuring successive samples. These were collected on September 30, October 17 and 25, and November 1. All samples were collected between 9:30 and 11 a.m. The material was thoroughly ground in a tinned meat chopper and passed through cheesecloth. The pH values were determined electrometrically. The results are shown in table 23.

TABLE 23.—*Effect of the quantity and the form of the nitrogen supplied in the fertilizer on the pH value of the cell sap of tobacco leaves from plants topped on September 3 and collected at intervals during the ripening period, season of 1919*

| Nitrogen added in the fertilizer | | pH value of expressed sap of— | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Samples taken immediately above the center of the stalk on— | | | | | | | | | Samples taken immediately below the center of the stalk on— | | | |
| Quantity per acre (pounds) | Form | Sept. 5 | Sept. 10 | Sept. 15 | Sept. 20 | Sept. 25 | Oct. 4 | Oct. 9 | Oct. 14 | Oct. 18 | Sept. 30 | Oct. 17 | Oct. 25 | Nov. 1 |
| None | | 6.36 | 6.23 | 6.17 | 6.20 | 6.12 | 6.23 | 6.36 | 6.03 | 6.12 | 6.02 | 5.99 | 5.89 | 5.60 |
| 20 | Nitrate of soda | 6.26 | 6.03 | 6.05 | 5.94 | 5.95 | 6.03 | 6.15 | 5.96 | 6.09 | 6.07 | 5.76 | 5.69 | ----- |
| 40 | do | 6.17 | 6.13 | 5.98 | 5.99 | 5.85 | 5.84 | 6.09 | 5.76 | 6.02 | 5.94 | 5.78 | 5.69 | ----- |
| 80 | do | 6.33 | 6.15 | 5.95 | 5.83 | 5.87 | 6.05 | 6.19 | 5.91 | 5.99 | 5.88 | 5.86 | 5.74 | 5.60 |
| 40 | Ammonium sulphate | 6.34 | 6.22 | 6.02 | 6.01 | 5.99 | 6.03 | 6.14 | 5.87 | 5.94 | 5.99 | 5.68 | 5.64 | ----- |
| 80 | do | ----- | ----- | ----- | 5.97 | 5.85 | 5.98 | 6.03 | 5.79 | 5.82 | 5.90 | 5.80 | 5.77 | ----- |

With increasing age of the leaves there was a definite downward trend in the pH number of the cell sap during September. This would indicate an increase in active acidity during the ripening process, and this relationship between the pH value and the stage of maturity of the leaf has been repeatedly observed. It is probable, in fact, that the progressive decrease in the pH number may be regarded as an indication of the progress of the ripening process. In the present experiment there was a decided rise in the pH figure during the first week of October, which went far toward restoring the original index of active acidity. During this period it was observed that the color of the leaves, which previously had been gradually assuming a lighter shade of green, changed to a darker green. Growers are familiar with this return toward a darker green color in tobacco leaves, which may occur during the progress of the ripening process as a result of wet weather. Under these conditions the

leaves are said to undergo a second growth in that they tend to return to the original, more vigorous state of vegetative activity. In the present case this change of condition, clearly indicated by the rise in the pH value, probably was due to a period of rainy and foggy weather which prevailed during the first week of October. Subsequently, with a change to clear weather, the increase in active acidity was resumed although a second temporary decrease occurred October 18. Through the remainder of the ripening period the active acidity continued to increase.

As regards the effect of the nitrogen supply, the leaf sap of plants receiving no nitrogen in the fertilizer showed consistently a relatively low active acidity till very late in the season. The form of the nitrogen apparently did not greatly affect the rate of increase of active acidity of the cell sap. Unfortunately, data could not be obtained on total titratable acidity in relation to nitrogen supply.

In 1925 a study was made of the content of nonvolatile organic acids in the leaf during the ripening period in relation to the nitrogen supply of the plant. Leaf samples were collected from the nitrate of soda series of plots 11 days before flowering, at flowering time, and 12 days after flowering. Each sample was composed of a single leaf from each of 15 selected plants, the leaves being taken from the center of the plants. The midribs were removed and the leaf material killed with chloroform vapor and dried. In addition to organic acids, total nitrogen and protein nitrogen were determined in the samples. The results are given in table 24.

TABLE 24.—*Effect of the content of nitrogen in the fertilizer applied to tobacco on the content of nonvolatile organic acids, total nitrogen, protein nitrogen, and nicotine of the leaves during the period of ripening, season of 1925*

| Time of sampling | Quantity of nitrogen applied per acre | Water content of fresh leaves | Composition of water-free leaf material | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | Citric acid | Malic acid | Oxalic acid | Total acids | Total nitrogen | Protein nitrogen | Nicotine |
| | *Pounds* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 11 days before flowering | None | 77.49 | 0.25 | 1.91 | 0.94 | 3.10 | 1.78 | 1.57 | 0.42 |
| | 20 | 79.97 | .02 | 2.11 | 1.32 | 3.45 | 2.47 | 2.04 | .67 |
| | 40 | 82.79 | .00 | 2.35 | 1.25 | 3.60 | 3.30 | 2.89 | .75 |
| | 80 | 82.25 | .15 | 2.54 | .82 | 3.51 | 3.37 | 2.94 | .73 |
| At time of flowering | None | 76.18 | .21 | 1.91 | 1.05 | 3.17 | 1.70 | 1.46 | .42 |
| | 20 | 76.96 | .16 | 2.60 | 1.12 | 3.88 | 1.78 | 1.65 | .65 |
| | 40 | 78.94 | .22 | 3.12 | 1.01 | 4.35 | 2.46 | 2.17 | .80 |
| | 80 | 80.48 | .30 | 3.37 | .89 | 4.56 | 2.94 | 2.47 | .83 |
| 12 days after flowering | None | 76.07 | .24 | 2.31 | 1.39 | 3.94 | 1.77 | 1.46 | .61 |
| | 20 | 76.20 | .25 | 2.77 | 1.28 | 4.30 | 1.76 | 1.43 | .83 |
| | 40 | 78.70 | .24 | 3.99 | 1.25 | 5.48 | 2.28 | 1.84 | 1.03 |
| | 80 | 79.88 | .84 | 4.29 | 1.15 | 6.28 | 2.85 | 2.28 | 1.46 |

As previously explained, the values for citric and malic acids that were obtained by the Kissling method cannot be considered as being accurate, but the data for oxalic acid are believed to be at least approximately correct and the values for citric probably afford a rough measure of the comparative content of this acid in the different samples. As a whole, the data for oxalic acid do not show any clearly defined trend during the period of observation while the content of citric acid tended to increase except when the nitrogen supply was deficient. There was a more pronounced increase in the fractions of somewhat uncertain composition which are designated collectively as malic acid. It is likely that other acids also were present in appreciable quantities in these fractions. Apparently the content of oxalic

acid was not greatly affected by the nitrogen supply of the plant, and this was true also of the citric acid content except that in the later stages of ripening a liberal nitrogen supply increased the content of this acid. The fraction designated as malic acid, however, showed quite consistently an increase as the nitrogen supply was increased.

### NITROGEN METABOLISM

In 1929 a series of 8 samples of leaf was taken at intervals covering a period of 47 days up to the flowering stage of the plants on the primary series of fertilizer plots receiving various quantities of nitrogen in the form of nitrate of soda. The same samples were used for a study of water relations in the plant, the results of which already have been considered, and the details of collecting and handling the material are described on page 40. Data were obtained on the changes in total area of the leaves, the weight of dry matter per unit of leaf area, and the content of total, protein, nitrate, nicotine, ammonia, amino, and amide nitrogen. As in the case of water content, data were secured on samples taken at the time of first flowering in both the first and second of the three groups of plants selected for the observations. (See table 20 for a summary of the results.)

In interpreting the results of the 1929 experiment it should be borne in mind that three different groups of plants were used in rotation as sources of the successive leaf samples. Thus, the samples collected 47 and 25 days before flowering and the first sample taken at time of flowering were derived from the same group of plants and, therefore, are more strictly comparable among themselves. Similarly, the samples taken 40 and 17 days before flowering and the second sample taken at time of flowering are strictly comparable, as are the samples taken 32 and 11 days before flowering. The plants were not topped prior to the beginning of flowering, the treatment in this respect approximating that commonly used in practical culture in Maryland and in the production of some types of leaf in other tobacco-growing districts. The leaves immediately above the lowermost were used in the studies, and these continued to increase in area up to the flowering stage, the increase being greatest with the heaviest rate of nitrogen fertilization, but there was no consistent change in weight of dry matter per square foot during the period of observation. In general, the dry weight per unit of area varied inversely with the rate of nitrogen fertilization. As regards both the physical and the chemical characteristics of the leaf in relation to the nitrogen supply, it should be recalled that, as shown in table 18, for some unknown reason the total quantity of nitrogen absorbed by the 1929 crop was only slightly greater in the 40-pound rate of fertilization than in the 20-pound rate. For practical purposes, therefore, the leaf samples from these two treatments may be regarded as duplicates and actually throughout table 20 the experimental data for the two series are seen to be in rather close agreement.

It is obvious that there was a marked loss of total nitrogen and an even greater proportionate decrease in protein nitrogen per unit of leaf area during the period of study, and these losses began more than a month before the flowering stage was reached. Since the total dry weight per unit of leaf area is recorded in table 20 it is a simple matter to ascertain the percentage content of the nitrogen fractions in the leaf, and the data for total nitrogen and protein nitrogen are presented graphically in figure 9. Here, again, there was in all

treatments a marked, progressive decrease in both total and protein nitrogen. Protein nitrogen accounted for about 79 percent of the total nitrogen at the beginning of the observational period, but at the end of the period the protein nitrogen composed only about

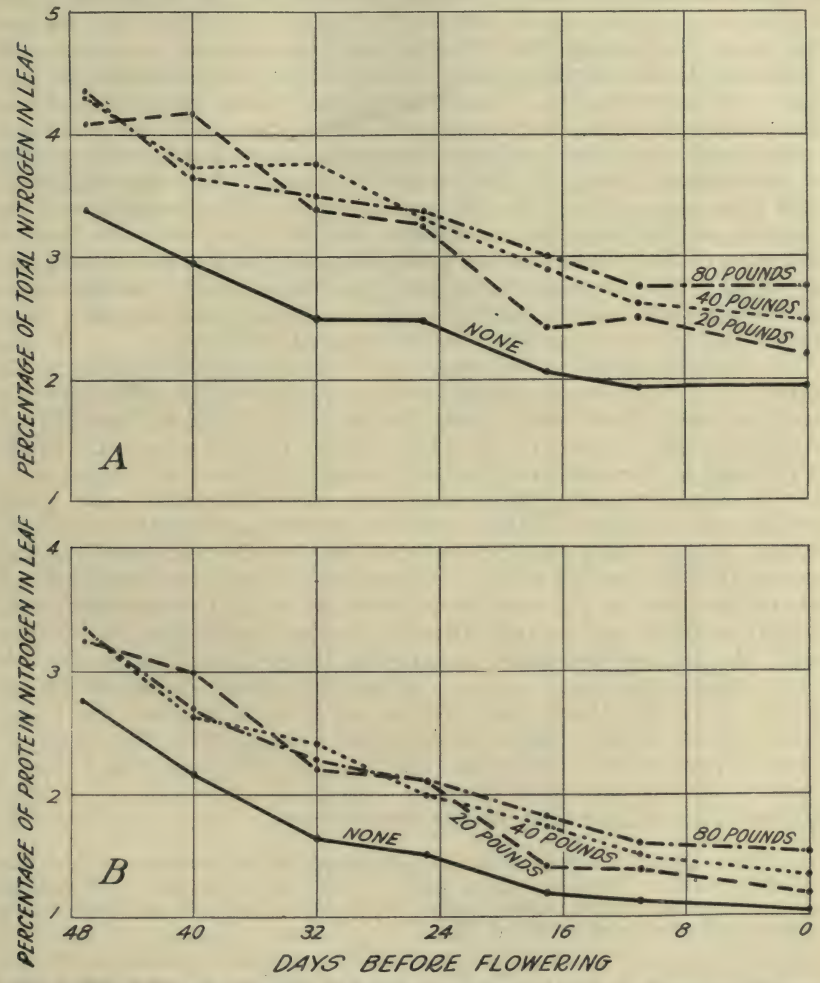


FIGURE 9.—Effect of the nitrogen supply on the percentage content of (*A*) total nitrogen and (*B*) protein nitrogen in the lower leaves of the plant during the later stages of their growth. There was a progressive decrease in both of the nitrogen values per unit of leaf area as well as on a percentage basis, which was due primarily to utilization of a portion of the nitrogen for increase in area of the leaves. Where no nitrogen was applied to the soil the total nitrogen and the protein nitrogen content of the leaf were low at all stages of growth, but otherwise differences in the quantity of nitrogen applied had little effect on the percentage content of these constituents until the last stages of growth had been reached.

54 percent of the total. This change, of course, involved a corresponding relative increase in nonprotein nitrogen. On the basis of unit area of leaf there was no marked change, however, in the actual content of nicotine, ammonia, amino, amide, and undetermined nitrogen during the period, while on the whole there was a tendency toward decrease in nitrate nitrogen. Next to protein, nicotine furnished decidedly the largest nitrogen fraction.

As regards the effect of variation in the nitrogen supply on the content of this element in the leaf, the data for the no-nitrogen or control treatment show in nearly all cases a uniformly low content of total nitrogen and of the various nitrogen fractions except the residual or undetermined portion. This holds true for the values calculated on the basis of unit area of leaf and in percentage of total dry matter. (See table 20, and fig. 9.) On the other hand, there are only small differences in the corresponding values for the various nitrogen fractions as between the 20-, 40-, and 80-pound rates of nitrogen fertilization, although it is worthy of note that frequently the nitrogen values for the intermediate rates of fertilization actually exceed those for the highest rate. In the case of the whole leaf the values for total nitrogen and protein nitrogen content vary directly with the quantity of the nitrogen supplied in the fertilizer. On the basis of unit area of leaf, the losses in total nitrogen and protein nitrogen in percentage of the quantities originally present, as well as the actual losses by weight taking place during the period of observation were highest with the intermediate rate of nitrogen fertilization.

The data obtained in 1924 and 1925 (tables 24 and 25) covering the period of 11 to 13 days before, to 11 to 12 days after, first flowering (and topping) show that in the developmental stages immediately following those covered in the 1929 studies, there was, on the whole, an increase in the content of total nitrogen and protein nitrogen with increase in rate of nitrogen fertilization. As in the latter case, where no nitrogen was used in the fertilizer, approximately the minimum content of total and protein nitrogen in the leaf had been reached several days before flowering. Where more nitrogen was made available to the plant in the soil, there were further sharp decreases in the content of total and protein nitrogen in the later stages of development, the general tendency apparently being toward a decrease to fairly definite minimum values. It seems that the higher the initial content of total nitrogen and protein nitrogen in the leaf, the longer is the time required for decrease of these constituents to the minimum values. Immediately following flowering and topping there was a sharp rise in the content of nicotine. Increase in the rate of nitrogen fertilization also increased the nicotine content.

TABLE 25.—*Effect of increasing the nitrogen supply in the fertilizer on the content of starch, sucrose, reducing sugars, total nitrogen, protein nitrogen, and total ash in the lower leaves of the tobacco plant, shortly before flowering, at flowering, and shortly after flowering, season of 1924*

| Time of sampling | Quantity of nitrogen in fertilizer per acre | Water content of leaf sample | Composition of dry matter in leaves | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Starch | Sucrose | Reducing sugars (as invert) | Total nitrogen | Protein nitrogen | Total ash |
| | *Pounds* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 13 days before flowering | 20 | 77.83 | 31.84 | 0.12 | 5.96 | 2.28 | 1.86 | 8.86 |
| | 40 | 78.60 | 29.74 | .08 | 6.72 | 2.51 | 2.20 | 8.62 |
| | 80 | 81.63 | 20.72 | .08 | 6.65 | 3.66 | 3.14 | 9.39 |
| At flowering | 20 | 78.75 | 31.60 | .09 | 5.29 | 1.81 | 1.45 | ------ |
| | 40 | 79.66 | 28.63 | .11 | 6.09 | 2.01 | 1.65 | 9.22 |
| | 80 | 81.70 | 15.14 | .02 | 6.37 | 3.42 | 2.70 | 10.38 |
| 11 days after flowering | 20 | 78.07 | 32.32 | .15 | 3.58 | 1.67 | 1.35 | 8.35 |
| | 40 | 78.06 | 26.35 | .15 | 3.74 | 1.78 | 1.38 | 8.53 |
| | 80 | 83.03 | 19.27 | .14 | 5.18 | 2.94 | 2.21 | 9.80 |

An attempt also was made in 1925 to secure data on the content of soluble protein in the cell sap of the leaf as affected by the quantity of nitrogen supplied in the fertilizer. Leaf samples were taken 10 days before flowering, at flowering, and 7 days after flowering. For each sample, a single leaf located near the center of the plant was taken from each of 15 selected plants. One half of each leaf was cut off and used as a source of the sap for analysis, while a series of disks were cut from the remaining half and, after being weighed, were placed in boiling alcohol for moisture determination. After freezing the leaf tissue, the sap was expressed by applying a fixed pressure to each sample. The official Stutzer method was employed for determining protein nitrogen in the sap and the residual nitrogen in the filtrate also was determined in the usual manner. It is recognized that the freezing treatment may have affected the solubility of the protein, and the Stutzer procedure may not afford an accurate measure of the soluble protein. However, the results probably are of value for purely comparative purposes. The data obtained are shown in table 26.

TABLE 26.—*Effect of increasing the nitrogen supply in the fertilizer on the content of soluble protein and nonprotein nitrogen in the cell sap of the leaf, season of 1925*

| Time of sampling | Quantity of nitrogen in the fertilizer per acre | Water content of leaf sample | Nitrogen in 10 cc of sap as— | |
|---|---|---|---|---|
| | | | Protein nitrogen | Nonprotein nitrogen |
| | *Pounds* | *Percent* | *Milligrams* | *Milligrams* |
| 10 days before flowering | None | 76.58 | 20.2 | 5.1 |
| | 20 | 79.39 | 19.0 | 6.9 |
| | 40 | 79.88 | 20.7 | 7.6 |
| | 80 | 82.37 | 25.0 | 9.6 |
| At flowering | None | 77.66 | 16.9 | 7.6 |
| | 20 | 77.62 | 16.9 | 4.1 |
| | 40 | 79.77 | 17.7 | 6.2 |
| | 80 | 82.15 | 21.5 | 7.3 |
| 7 days after flowering | None | 78.12 | 12.4 | 5.1 |
| | 20 | 77.78 | 12.4 | 6.5 |
| | 40 | 80.16 | 14.1 | 7.7 |
| | 80 | 82.28 | 19.5 | 10.5 |

The data for the nitrogen fraction of the cell sap designated as soluble protein show much the same relations as apply to total protein and total nitrogen in the leaf during approximately the same stages of development (table 26). There is in all cases a definite decrease in soluble protein as the leaf ages or matures, though the rate of decrease is relatively slow when the maximum rate of nitrogen fertilization is practiced and is highest when no nitrogen is included in the fertilizer. There is no corresponding progressive decrease in the nonprotein nitrogen in the sap. As to the effect of nitrogen fertilization, the first 20 pounds of nitrogen in the fertilizer shows no material influence on the content of soluble protein, but additional increments of fertilizer nitrogen and more particularly the 80-pound rate of fertilization bring about a clearly defined increase in protein content of the sap. Increased nitrogen in the fertilizer also tends to increase the content of nonprotein nitrogen in the sap.

### CARBOHYDRATE METABOLISM

In 1926 a study was made of the effect of increasing the supply of nitrogen in the fertilizer on the carbohydrate content of the leaf during the period of growth preceding the flowering stage. A series of leaf samples was collected from the primary series of fertilizer plots receiving various quantities of nitrogen derived from nitrate of soda, the samples being taken 41, 32, 24, and 18 days, respectively, before the date of first flowering. The method of collecting, handling, and preparing the material was the same as for the 1929 study of nitrogen metabolism (p. 46) except that for each fertilizer treatment only a single group of plants was used for all samples. The leaves were taken from the lower half of the plant, the final sample consisting of the twelfth leaf from the bottom in each case. The analytical data are shown in table 27.

TABLE 27.—*Effect of increasing the nitrogen supply in the fertilizer on the content of total dry matter, starch, sucrose, and reducing sugars in the lower leaves of the tobacco plant during the period of growth preceding the flowering stage, season of 1926*

| Number of days before flowering | Quantity of nitrogen in fertilizer per acre | Water content of leaf sample | Weight of dry matter per square foot | Carbohydrate in 1 square foot of leaf | | |
|---|---|---|---|---|---|---|
| | | | | Starch | Sucrose | Reducing sugars (as invert) |
| | *Pounds* | *Percent* | *Grams* | *Milligrams* | *Milligrams* | *Milligrams* |
| 41 | None | 84.47 | 4.076 | 938.0 | 18.6 | 282.4 |
| | 20 | 86.76 | 3.455 | 216.3 | 5.9 | 128.7 |
| | 40 | 86.78 | 3.473 | 202.5 | 21.6 | 177.2 |
| | 80 | 86.38 | 3.517 | 241.4 | 5.5 | 177.1 |
| 32 | None | 85.87 | 3.356 | 477.7 | 4.6 | 135.4 |
| | 20 | 87.33 | 3.124 | 151.5 | 3.6 | 57.3 |
| | 40 | 86.74 | 3.288 | 184.5 | 3.9 | 97.9 |
| | 80 | 86.53 | 3.370 | 202.0 | 6.1 | 100.3 |
| 24 | None | 86.35 | 3.328 | 345.3 | 7.4 | 153.1 |
| | 20 | 86.39 | 3.304 | 168.3 | 7.7 | 154.2 |
| | 40 | 86.27 | 3.417 | 188.5 | 2.4 | 178.0 |
| | 80 | 87.20 | 3.373 | 98.3 | 3.1 | 136.6 |
| 18 | None | 84.89 | 3.662 | 309.2 | 6.2 | 162.1 |
| | 20 | 83.92 | 3.943 | 310.9 | 2.8 | 196.8 |
| | 40 | 84.83 | 3.849 | 200.6 | 2.4 | 205.7 |
| | 80 | 85.49 | 3.808 | 119.5 | 9.8 | 157.9 |

In 1924, leaf samples were taken from the same plots, except as to the control or no-nitrogen treatment, as in the 1926 experiment, the samples being collected 13 days before flowering, at flowering, and 11 days after flowering. Determinations were made of total nitrogen, protein nitrogen, and ash in addition to estimating the content of starch, sucrose, and reducing sugars. The results expressed in percentages of total dry matter are summarized in table 25.

The observations made in 1926 show that the starch content was decidedly high when the nitrogen supply was very low, especially in the earlier stages of growth. An addition of only 20 pounds per acre to the nitrogen supply of the soil greatly reduced the content of starch while there was comparatively little difference as to this constituent between leaves of plants receiving 20 pounds of nitrogen

per acre in the fertilizer and those of plants fertilized with 80 pounds of nitrogen. As the flowering stage was approached there was in general a temporary decrease in the leaf content of starch. Differences in content of reducing sugars were less clearly defined either with respect to increasing age of the leaves or increase in the nitrogen supply of the soil.

The data obtained in 1924 show that in the developmental stages immediately following those covered in the 1926 test there may be a decidedly high content of starch in the leaf when the quantity of nitrogen in the fertilizer is low and again the percentage of starch decreases as the nitrogen supply is increased. The content of reducing sugars seems to increase somewhat with increase in the nitrogen supply though the differences are not large. The quantity of sucrose in the leaf is rather small. As in the experiments previously discussed, an increased supply of nitrogen in the fertilizer results in an increased content of total nitrogen and protein nitrogen in the leaf. The limited data available show a slight increase in total ash content of the leaf with increase in the nitrogen supply of the plant.

### OBSERVATIONS ON OXIDIZING ENZYMES

In 1925 and 1926 a number of measurements of catalase activity were made on leaf material taken from the nitrogen test plots and from other sources during the period of growth and the subsequent ripening process. Only a portion of the results obtained will be presented in detail. In carrying out the tests a number of small disks of known area were cut from definite positions on the leaf by means of a sharp cork borer. The material was ground in a mortar to a fine cream after addition of a little water and calcium carbonate, the mixture then being washed into a 250 cc Florence flask with a small measured volume of water. After placing the flask in a water bath at 25° C. and connecting it with a shaking device the volume of oxygen liberated in 15 minutes by addition of Oakland hydrogen dioxide that had been previously treated with calcium carbonate was collected and measured in the usual manner. All results were calculated to a uniform basis of 25° C. A duplicate sample of leaf material was treated with hot alcohol and used to determine the approximate content of dry matter and water in the test material per unit of area. In this way the results could be calculated on a basis of unit area or in percentages of total fresh weight and total dry matter.

Preliminary observations were made on the relative catalase activity of leaves located on the lower, middle, and upper portions of the stalk. The results invariably showed the lowest activity in the lower leaves. As between the upper and the middle leaves the results were dependent primarily on the size or stage of development attained by the former. Where the upper leaves had reached a fairly large size they were more active than the middle leaves, but in younger stages they were less active than the latter. The data, as a whole, give definite indication that the catalase activity of a given leaf normally increases up to the later stages of growth followed after a time by a gradual decline as the leaf ages. Catalase activity, however, appears to be subject to rather wide fluctuations from day to day.

In 1925, measurements were made on the activity of middle leaves of selected plants on the plots of the primary series receiving nitrogen at various rates. The plants were topped at the beginning of the flowering stage and samples were collected 1, 9, and 15 days, respectively, after topping. The results are contained in table 28.

TABLE 28.—*Effect of variation in the quantity of nitrogen supplied in the fertilizer on the catalase activity of tobacco leaves during the ripening period, season of 1925*

| Number of days after flowering | Quantity of nitrogen in the fertilizer per acre | Volume of oxygen liberated from— | | Number of days after flowering | Quantity of nitrogen in the fertilizer per acre | Volume of oxygen liberated from— | |
|---|---|---|---|---|---|---|---|
| | | 1 sq. in. of leaf | 0.5 gram of fresh leaf | | | 1 sq. in. of leaf | 0.5 gram of fresh leaf |
| | *Pounds* | *Cc* | *Cc* | | *Pounds* | *Cc* | *Cc* |
| 1 | None | 14.6 | 55.3 | 9 | 40 | 14.2 | 54.3 |
| | 20 | 12.9 | 50.5 | | 80 | 32.9 | 126 |
| | 40 | 10.4 | 44.6 | 15 | None | 15.8 | 55.0 |
| | 80 | 21.1 | 85.9 | | 20 | 12.7 | 50.5 |
| 9 | None | 14.3 | 56.5 | | 40 | 22.6 | 83.3 |
| | 20 | 18.1 | 72.8 | | 80 | 39.1 | 146 |

It appears that in the 1925 experiment the catalase activity of the middle leaves of the plant had already reached a maximum at the time of first flowering where no nitrogen was used in the fertilizer, while with the heavier rates of nitrogen fertilization there was a marked further increase in activity during the following 2 weeks. At all stages a high nitrogen supply resulted in increased catalase activity.

In 1927, studies were made of peroxidase activity in the fresh leaf of plants from the same plots that were employed for the experiments dealing with catalase activity. The method of sampling the leaves was the same as for the catalase tests, the disk samples being taken from one half of each leaf and the other half left intact for tests on curing (p. 58). Leaves located approximately at the middle of the stalk were used for sampling. The samples were taken 5, 13, and 18 days after first flowering and topping. The fresh leaf material was finely ground in a mortar with a little water and calcium carbonate and the peroxidase determined according to the method of Willstätter (*28*). The results expressed in milligrams of purpurogallin on a basis of 0.2 gram of both the fresh and the dry leaf tissue are shown in part in table 29.

TABLE 29.—*The peroxidase number of tobacco leaves during the ripening period, season of 1927, as affected by the quantity of nitrogen supplied in the fertilizer*

| Quantity of nitrogen in fertilizer per acre (pounds) | Purpurogallin obtained from 0.2 g of leaf material— | | | | | |
|---|---|---|---|---|---|---|
| | 5 days after topping | | 13 days after topping | | 18 days after topping | |
| | Fresh leaf | Dry leaf | Fresh leaf | Dry leaf | Fresh leaf | Dry leaf |
| | *Milligrams* | *Milligrams* | *Milligrams* | *Milligrams* | *Milligrams* | *Milligrams* |
| None | 8.41 | 33.48 | 10.46 | 39.64 | | |
| 20 | 8.64 | 34.58 | 13.58 | 49.55 | 13.60 | 47.58 |
| 40 | 8.36 | 36.58 | 14.37 | 55.62 | | |
| 80 | 12.41 | 61.83 | 16.56 | 78.62 | 16.83 | 80.54 |

Increase in the nitrogen supply of the plant tends to increase the peroxidase number of the leaf, this effect being especially evident in the highest rate of nitrogen fertilization. The peroxidase value also increases considerably through the period of 2 weeks immediately following first flowering. In experiments with plants fertilized with 80 pounds of nitrogen per acre derived from nitrate of soda, ammonium sulphate, and ammonium chloride, respectively, the results were somewhat variable and would hardly justify definite conclusion as to possible significant differences in the effects of nitrogen from these three sources.

#### EFFECTS OF HIGH AND LOW TOPPING ON GROWTH AND METABOLISM

In some important tobacco-growing sections it is the usual practice to top the plants low and the topping is done several days before flowering would begin. It is desirable, therefore, to consider briefly the primary effects of low topping on the ripening process. Observations were made on two plots in 1930 which were fertilized with 100 pounds of nitrate of soda, 300 pounds of 16-percent superphosphate, and 200 pounds of high-grade sulphate of potash per acre. The season was an extraordinarily dry one. One plot was located on a slight elevation, with the result that the crop was more severely affected by the drought than that of the other plot which was located on a lower area. For convenience, the plots will be referred to as dry land and moist land. The tobacco made much better growth on the latter soil than on the former. On each plot three groups of 25 uniform plants each were selected for study. On the dry land one group was topped to 16 leaves and a second group was topped to 8 leaves, while on the moist land the respective groups were topped to 18 and 9 leaves. In each case the control groups remained untopped. The topping was delayed until flowering had begun, in order to maintain comparison with all of the preceding experiments. Under these conditions the maximum effects of low topping probably were not obtained. The first samples, consisting of the fifth leaf from the bottom of each plant on the dry land and the sixth leaf of each plant on the moist land, were taken at time of topping. Subsequently samples consisting in each case of the next higher leaf were taken at intervals of 10 to 12 days. The last sample taken on the moist land was subjected to curing, while all others were exposed to chloroform vapor and dried in the usual way. The average area, the water content, and the dry weight per unit area were ascertained and protein, nicotine, and total nitrogen were determined in the dried material. The results are indicated in table 30.

TABLE 30.—*Effect of high and low topping on the ripening process in the leaf in the field and on the cured product, season of 1930*

| Type of soil and treatment of plants | Time of sampling | Area of 10 leaves | Water content of leaf | Dry weight of leaf per square foot | Nitrogen in 1 square foot of leaf as— | | | Nicotine in dry leaf |
|---|---|---|---|---|---|---|---|---|
| | | | | | Total nitrogen | Protein nitrogen | Nicotine nitrogen | |
| | | *Sq. ft.* | *Percent* | *Grams* | *Milligrams* | *Milligrams* | *Milligrams* | *Percent* |
| Dry land: | | | | | | | | |
| Not topped | At topping | 7.82 | 76.70 | 5.754 | 135.8 | 97.8 | 17.8 | 1.79 |
| Topped high | do | 8.02 | 77.84 | 5.669 | 137.7 | 96.9 | 18.9 | 1.93 |
| Topped low | do | 7.71 | 76.95 | 5.800 | 138.6 | 98.0 | 18.2 | 1.82 |
| Not topped | 10 days after topping | 7.59 | 77.86 | 5.352 | 130.0 | 87.8 | 20.8 | 2.25 |
| Topped high | do | 7.53 | 77.32 | 5.539 | 135.7 | 88.6 | 23.4 | 2.44 |
| Topped low | do | 7.59 | 76.72 | 5.929 | 163.6 | 103.7 | 29.2 | 2.85 |
| Not topped | 21 days after topping | 6.71 | 76.04 | 5.822 | 128.7 | 85.6 | 20.5 | 2.04 |
| Topped high | do | 7.05 | 74.82 | 6.349 | 149.8 | 92.1 | 29.1 | 2.65 |
| Topped low | do | 7.04 | 77.32 | 6.360 | 192.1 | 117.7 | 38.0 | 3.46 |
| Not topped | 31 days after topping | 5.87 | 76.14 | 5.500 | 135.8 | 90.2 | 21.3 | 2.24 |
| Topped high | do | 6.42 | 75.56 | 6.228 | 167.5 | 101.5 | 36.9 | 3.43 |
| Topped low | do | 6.79 | 78.84 | 6.700 | 251.9 | 144.0 | 58.5 | 5.05 |
| Moist land: | | | | | | | | |
| Not topped | At topping | 11.33 | 80.22 | 5.205 | 161.3 | 120.2 | 16.4 | 1.83 |
| Topped high | do | 11.14 | 80.37 | 5.109 | 163.5 | 121.1 | 18.2 | 2.06 |
| Topped low | do | 11.57 | 80.26 | 5.190 | 168.7 | 127.1 | 17.0 | 1.90 |
| Not topped | 12 days after topping | 11.32 | 80.65 | 4.814 | 144.4 | 101.1 | 19.7 | 2.37 |
| Topped high | do | 11.99 | 79.57 | 5.178 | 156.4 | 107.7 | 24.2 | 2.71 |
| Topped low | do | 11.71 | 78.37 | 5.729 | 192.5 | 127.2 | 32.0 | 3.23 |
| Not topped | 24 days after topping | 10.92 | 79.81 | 4.915 | 152.4 | 104.2 | 22.6 | 2.67 |
| Topped high | do | 11.02 | 78.93 | 5.210 | 168.3 | 106.3 | 31.0 | 3.45 |
| Topped low | do | 11.54 | 78.39 | 6.349 | 246.3 | 146.7 | 50.7 | 4.62 |
| Not topped | 28 days after topping | 10.05 | -------- | [1] 4.309 | -------- | -------- | -------- | -------- |
| Topped high | do | 10.14 | -------- | [1] 4.571 | -------- | -------- | -------- | -------- |
| Topped low | do | 10.86 | -------- | [1] 6.023 | -------- | -------- | -------- | -------- |

[1] After curing.

The abnormally dry weather greatly restricted the growth of all leaves except the lower ones on the plants, with the result that in successive samples there is a definite decrease in area which ordinarily would not be the case. The smaller size of the leaves in the dry-land series as compared with those in the moist-land series is associated with a decreased water content. On the other hand, the dry weight per unit of area is decidedly greater on the dry land, especially for the untopped and the high-topped plants. The nitrogen content of the leaves from the moist land is considerably higher than that of the leaves from the dry land, particularly on a percentage basis.

Topping the plants increased the area of the leaf during the period of observation when comparison is made with the untopped plants, that is, there was less decrease in area of the leaves in advancing up the stalk when the plants were topped. The weight of dry matter per square foot of leaf was decidedly increased as a result of topping, the low topping producing the greatest increase. In the plants not topped there was an actual decrease in dry weight per unit of area. The effect of topping on dry weight was especially marked after the leaf had been cured, the increase over the untopped plants being nearly 40 percent. On a percentage basis the data in table 30 do not indicate any considerable, consistent increase in water content as a result of topping because of the definite increase in dry matter. The absolute quantity of water per unit area of the leaf, however, is definitely increased by the topping.

During the period of observation there was a tendency toward decrease in total nitrogen and protein nitrogen in the leaves of the

plants that were not topped although the losses were partly recovered in the late stages of ripening. In the plants topped high there were no important changes in total or protein nitrogen though there was a moderate gain in total nitrogen in the dry-land series and a small loss of protein nitrogen in the moist-land series. In the low-topped plants, on the other hand, there was a very striking, progressive increase in total nitrogen and a somewhat less pronounced increase in protein nitrogen. On the dry land the increase in total nitrogen per unit of area reached approximately 80 percent and that of protein nitrogen more than 45 percent. Nicotine showed only a slight increase in the untopped plants during the period of observation. In the high-topped plants the increase was much greater and in the low-topped plants it amounted to more than 200 percent.

Opportunity was found for making observations in 1931 on a different series of plots pertaining to the effects of high and low topping in conjunction with variations in rate of nitrogen fertilization on the catalase activity of the leaf during the ripening period. All plots were fertilized uniformly with 64 pounds of phosphoric acid and 96 pounds of potash per acre while one group of plots received no nitrogen and the other two groups received 32 and 128 pounds, respectively. In each group one plot remained untopped, a second was topped to the lowermost leafless sucker, and the third was topped to 10 leaves. The low topping was done when the flower bud appeared above the leaves, and the high topping was done on date of first flowering. Except where no nitrogen was used in the fertilizer the low topping was carried out on August 4 and the high topping on August 13. Because of delayed development where nitrogen was omitted from the fertilizer the respective dates of topping were postponed until August 24 and September 9. The methods of sampling and conducting the analysis were the same as previously employed. For the first series of readings in each treatment the fifth leaf from the bottom was chosen, and for the second series the eighth or ninth leaf was selected. Where no nitrogen was used in the fertilizer the first sample was taken 9 days after the low topping and 7 days prior to the high topping and the second sample was taken 13 days later. In the other two treatments the first samples were taken 2 days after the low topping and 7 days prior to the high topping and the second samples were taken 26 or 27 days later. The results are summarized in table 31.

TABLE 31.—*Effect of height of topping and variation in rate of nitrogen fertilization on the catalase activity of tobacco leaves during the ripening period, season of 1931*

| Quantity of nitrogen in the fertilizer per acre (pounds) | Date of sample | Volume of oxygen liberated from 1 square inch of leaf in— | | | Quantity of nitrogen in the fertilizer per acre (pounds) | Date of sample | Volume of oxygen liberated from 1 square inch of leaf in— | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Controls | Plants topped high | Plants topped low | | | Controls | Plants topped high | Plants topped low |
| | | *Cc* | *Cc* | *Cc* | | | *Cc* | *Cc* | *Cc* |
| None | Sept. 2 | 21.9 | 16.0 | 28.2 | None | Sept. 15 | 33.7 | 22.1 | 41.0 |
| 32 | Aug. 6 | 26.2 | 29.2 | 30.9 | 32 | Sept. 2 | 33.5 | 31.8 | 53.0 |
| 128 | do | 43.0 | 45.6 | 44.3 | 128 | Sept. 1 | 49.9 | 58.0 | 74.4 |

It is apparent that low topping of the plants produced a decided effect in increasing the catalase value, especially when the rate of nitrogen fertilization was high. However, high topping produced no effect except possibly a slight increase in the case of the heavy rate of nitrogen fertilization.

## THE NITROGEN SUPPLY AND THE CURING PROCESS

The data bearing on the effects of the nitrogen supply on nutritional and growth processes during the development of the tobacco plant make it plain that at time of harvest the physical and chemical characteristics of the leaf will depend to a considerable extent on the quantity of nitrogen absorbed and assimilated by the plant. The regulated rate of drying to which the freshly harvested leaves are subjected, commonly known as curing, involves complex, deep-seated changes in composition in addition to the loss of water. Radically different methods of curing are applied to the various types of tobacco, the air-curing and the flue-curing methods perhaps providing the widest contrast. Air curing is a relatively slow procedure conducted at ordinary temperatures, while flue curing is a rapid process involving use of comparatively high temperatures. In Maryland air curing is generally applied and the leaves remain attached to the stalk until the cure has been completed.

In the present investigations no attempt was made to follow through the different stages of the curing the effect of the nitrogen supply on all of the various chemical processes that are involved, but a limited number of observations were made on certain features. In 1927, leaf samples were collected from the middle portion of plants on the plots receiving various quantities of nitrogen derived from nitrate of soda, the samples being taken just before harvest. After obtaining the fresh weights and areas of the leaves, the midribs were removed and one half of each leaf was chloroformed and quickly dried, while the remaining leaf halves were cured in the usual manner. The loss in total dry matter was ascertained and the material was utilized for determining the resin content before and after curing, according to the method of Degrazia (*8*). The results are brought together in table 32. The several components of the resin mixture were estimated separately, but no clearly defined differences in the various fractions were found so that only the total content of resins is shown in the table.

TABLE 32.—*Effect of the nitrogen supply on the loss of total dry matter and on the content of total resins in the leaf during the air-curing process, season of 1927*

| Quantity of nitrogen in the fertilizer per acre (pounds) | Average area of leaves | Moisture in fresh leaf | Weight of dry matter in leaf per square foot | | Loss of dry matter in curing | Resin content of dry leaf | |
|---|---|---|---|---|---|---|---|
| | | | Fresh | Cured | | Fresh | Cured [1] |
| | *Sq. ft.* | *Percent* | *Grams* | *Grams* | *Percent* | *Percent* | *Percent* |
| None | 0.7879 | 75.14 | 6.053 | 4.777 | 21.07 | 3.63 | 4.42 |
| 20 | 1.1605 | 75.87 | 5.486 | 4.341 | 20.86 | 4.50 | 5.27 |
| 40 | 1.2419 | 78.35 | 5.526 | 4.311 | 21.99 | 4.82 | 5.66 |
| 80 | 1.4096 | 81.58 | 4.601 | 3.574 | 22.33 | 4.96 | 5.23 |

[1] Data calculated on a basis of dry matter in the fresh leaf.

Variations in nitrogen supply did not greatly affect the loss in total dry matter in curing although the loss was somewhat greater in the leaves of plants grown with an increased supply of nitrogen. The values for so-called resins apply to a group of poorly defined constituents determined by an empirical procedure and their exact significance is not known. The values for resin content of the cured leaf, when calculated on the basis of the original weight of the uncured leaf, seem to indicate a definite increase in some of the constituents included in this group during the curing process. Although in this particular experiment the tobacco which received no nitrogen in the fertilizer shows a relatively low content of resins, the data for the leaf from the other treatments do not indicate that the nitrogen supply is an important factor in the content of total resins in tobacco leaf.

Since the effect of the curing process on the content of oxidizing enzymes previously had not been studied extensively it seemed desirable to obtain additional information on this subject, particularly since there is reason to believe that these enzymes play an important role in the fermentation and ageing processes which follow the curing. In this connection it should be noted that Smirnow and Drboglav (*23*) found that the catalase and peroxydase activity increases in green leaves of oriental yellow tobacco subjected to regulated conditions of starvation. A number of preliminary tests were made to ascertain the normal course of catalase activity in mature leaves through the various stages of air curing. The data uniformly showed an appreciable rise in activity in the first stages of curing, this usually occurring in the first 2 or 3 days. Thereafter a sharp decline in activity was observed, and at the end of 10 days or 2 weeks the decrease was such that in some instances the order of magnitude of the catalase activity coefficient had changed. In a representative case the initial coefficient of catalase activity of 56 per square inch of leaf increased to 78 on the second day and at the end of 9 days had fallen to 9.

In connection with the studies on catalase activity during the curing process it was found that exposure of the fresh, green leaf to vapors of chloroform results in a rapid and very marked decrease in catalase activity. For example, in a sample of the fresh leaf dried rapidly in a current of air at ordinary temperature the coefficient of catalase activity was 48.9 while in a similar sample exposed to chloroform before drying the catalase value had fallen to 3.5. The action of chloroform vapor in diminishing catalase activity was found to proceed much more slowly after the leaf has been dried and again moistened. Exposure of the above-mentioned dried-leaf sample to chloroform vapor for 2½ hours produced no measurable effect on the coefficient of activity, while an exposure of 42 hours decreased the coefficient to 7.5 as compared with a value of 14.2 for the control sample not treated with chloroform.

In 1926, groups of plants were selected on the plots receiving in the fertilizer 80 pounds of nitrogen per acre derived from nitrate of soda, ammonium sulphate, and ammonium chloride, respectively, and on a control plot, and leaf samples were taken from the middle portion of the plants for observations on relative catalase activity during the curing. At time of sampling, the plants on the plot receiving no nitrogen showed a uniform light yellowish-green color and in this respect would be regarded as fully mature. The plants fertilized with nitrate of soda appeared to be only slightly less mature than the

controls, while those fertilized with ammonium sulphate appeared to be somewhat less mature and those receiving nitrogen from ammonium chloride seemed to be the least mature of all in the series. After cutting small disks from the leaves for determination of catalase they were allowed to cure in the usual way, four successive disk samples being taken at intervals of 2 to 3 days. The results are given in table 33.

TABLE 33.—*Effect of the nitrogen supply on catalase activity of the leaf during the curing process, season of 1926*

| Nitrogen supplied in fertilizer | | Sept. 14 [1] | Sept. 16 | Sept. 18 | Sept. 21 | Sept. 24 |
|---|---|---|---|---|---|---|
| Quantity per acre (pounds) | Form | | | | | |
| | | VOLUME OF OXYGEN LIBERATED FROM 1 SQUARE INCH OF FRESH LEAF | | | | |
| | | *Cc* | *Cc* | *Cc* | *Cc* | *Cc* |
| None | | 46 | 19 | 24 | 9 | 4 |
| 80 | Ammonium chloride | 116 | 74 | 125 | 57 | 15 |
| 80 | Ammonium sulphate | 98 | 62 | 49 | 19 | 4 |
| 80 | Nitrate of soda | 87 | 67 | 84 | 36 | 7 |
| | | VOLUME OF OXYGEN LIBERATED FROM 0.1 G OF DRY LEAF | | | | |
| None | | 136 | 51 | 72 | 27 | 13 |
| 80 | Ammonium chloride | 321 | 217 | 389 | 183 | 49 |
| 80 | Ammonium sulphate | 311 | 188 | 193 | 64 | 17 |
| 80 | Nitrate of soda | 269 | 189 | 259 | 106 | 26 |

[1] Date of harvest.

From the results of this experiment it appears that although initially the mature leaves grown with a high nitrogen supply possessed a relatively high catalase activity, as the curing progressed the rate of decrease in activity was correspondingly greater than in the leaves grown with a low nitrogen supply (the controls). The initial activity was greatest and the rate of loss of activity was the least in the leaves of plants fertilized with nitrogen derived from ammonium chloride. This result was possibly due in part to the fact that the leaves from this treatment were less mature when harvested than the others, and in part to the effect of the chloride ion in slowing down the rate of drying.

In 1927, studies were made on the effect of the nitrogen supply on peroxidase activity during the curing process in continuation of the observations made during the ripening period in the field (p. 52). The same leaf samples were utilized, and the method of determination was the same. The leaves were allowed to cure for 22 days. The results are assembled in table 34.

TABLE 34.—*Effect of the nitrogen supply on peroxidase activity of the leaf during the curing process, season of 1927*

| Quantity of nitrogen in the fertilizer per acre (pounds) | Purpurogallin obtained from— | | | |
|---|---|---|---|---|
| | 1 square inch of leaf | | 0.2 g of dry leaf material | |
| | Fresh | Cured | Fresh | Cured |
| | *Milligrams* | *Milligrams* | *Milligrams* | *Milligrams* |
| None | 7.4 | 5.7 | 39.6 | 29.2 |
| 20 | 9.4 | 7.5 | 49.6 | 40.4 |
| 80 | 11.9 | 9.6 | 78.6 | 59.1 |

The data in table 34 show that there is an appreciable decrease in the peroxidase value during the curing although this decrease seems to be much smaller than that of catalase. The results are much the same whether the data are based on equal areas or equal weights of the leaf. In both the cured and the green material the peroxidase number is increased by an increased supply of fertilizer nitrogen.

## CHEMICAL COMPOSITION OF CURED TOBACCO AS AFFECTED BY THE NITROGEN SUPPLY

In 1925, groups of 32 representative plants each were selected from the plots fertilized with 20, 40, and 80 pounds of nitrogen per acre derived from nitrate of soda and from a control plot receiving no nitrogen. The plants were topped, harvested, and cured according to the usual practice in southern Maryland. When the curing was completed the leaves were stripped from the stalks, ground, and preserved for chemical analysis. The midribs of the leaves were not removed in preparation for analysis. The prepared samples were composed of all the leaves secured from the cured plants, so that in each case the composition represents the average for all the grades of leaf produced under the conditions of the experiment. In the analysis nearly all organic constituents were determined insofar as analytical methods were available even though in some cases it was recognized that the methods employed are not entirely satisfactory. The principal ash constituents also were determined. The tobacco samples were found to contain large percentages of fine earth, and proper correction for this material was applied to all analytical data. The results are shown in tables 35 and 36.

TABLE 35.—*Effect of quantity of nitrogen in the fertilizer on the composition of cured leaf tobacco on a water-free basis, crop of 1925*

| Constituents | Percentage of constituents found in leaves from plants fertilized with— | | | |
|---|---|---|---|---|
| | No nitrogen | 20 pounds of nitrogen per acre | 40 pounds of nitrogen per acre | 80 pounds of nitrogen per acre |
| | *Percent* | *Percent* | *Percent* | *Percent* |
| Starch | 4.34 | 3.34 | 2.42 | 1.52 |
| Reducing sugars (as invert) | 1.48 | 1.40 | 1.28 | .59 |
| Sucrose | .32 | .20 | .15 | .20 |
| Cellulose (crude fiber) | 16.07 | 17.20 | 16.99 | 16.60 |
| Pectic acid (as calcium pectate) | 14.93 | 16.01 | 14.00 | 15.05 |
| Protopectin (as calcium pectate) | 1.24 | .70 | 1.63 | .09 |
| Protein | 7.50 | 9.06 | 8.63 | 11.50 |
| Nicotine | .63 | .73 | 1.24 | 1.46 |
| Nitric acid ($N_2O_5$) | .09 | .09 | .11 | .58 |
| Ammonia | .08 | .06 | .10 | .19 |
| Citric acid | 1.17 | 1.46 | 1.67 | 3.36 |
| Malic acid | 3.16 | 4.07 | 4.98 | 5.32 |
| Oxalic acid | 1.53 | 1.77 | 1.68 | 1.50 |
| Plant wax | .34 | .20 | .31 | .17 |
| Total resins | 6.55 | 5.60 | 5.57 | 5.81 |
| Resene | 4.40 | 3.76 | 4.08 | 4.04 |
| Alpha-tobaccic acids | .79 | .74 | .67 | .69 |
| Beta-tobaccic acids | .75 | .62 | .45 | .69 |
| Gamma-tobaccic acids | .55 | .37 | .37 | .31 |
| Resin alcohol | .06 | .11 | .00 | .08 |
| Total ash | 14.70 | 12.88 | 14.47 | 14.96 |
| Potash | 3.36 | 2.96 | 2.19 | 2.23 |
| Calcium oxide | 4.90 | 5.11 | 5.58 | 5.12 |
| Magnesia | 1.73 | 1.58 | 1.62 | 1.73 |
| Phosphoric acid ($P_2O_5$) | .64 | .48 | .48 | .43 |
| Total sulphur (as $SO_3$) | 1.48 | 1.50 | 1.45 | 1.30 |
| Chlorine | .16 | .37 | .28 | .35 |
| Total nitrogen | 1.81 | 2.18 | 2.30 | 3.06 |

TABLE 36.—*Effect of quantity of nitrogen in the fertilizer on the distribution of the nitrogen in cured leaf tobacco, season of 1925*

| Form of nitrogen | Distribution of nitrogen found in leaves from plants fertilized with— | | | |
|---|---|---|---|---|
| | No nitrogen | 20 pounds of nitrogen per acre | 40 pounds of nitrogen per acre | 80 pounds of nitrogen per acre |
| | *Percent* | *Percent* | *Percent* | *Percent* |
| Total | 100 | 100 | 100 | 100 |
| Protein | 66.30 | 66.51 | 60.00 | 60.13 |
| Nicotine | 6.11 | 5.95 | 9.13 | 8.17 |
| Amide | 3.31 | 2.02 | 4.09 | 5.26 |
| Amino | 8.23 | 5.55 | 7.52 | 7.90 |
| Nitrate | 1.32 | 1.10 | 1.22 | 4.87 |
| Ammonia | 3.70 | 2.34 | 3.74 | 5.16 |
| Undetermined | 11.03 | 16.53 | 14.30 | 8.51 |

On the whole, the influence of increasing the nitrogen supply in the fertilizer on the chemical composition of the cured leaf is not particularly striking, but some clearly defined effects of importance are apparent. With increasing quantities of nitrogen applied to the soil there is a progressive decrease in content of starch and sugars. Insofar as the values for crude fiber are indicative of the content of cellulose, change in the nitrogen supply seems to have no significant effect on this constituent of the cell wall. The values for pectins are somewhat irregular, but there is indication that a high nitrogen supply tends to reduce slightly the pectin content. None of the samples contained appreciable quantities of water-soluble pectin. The data for protein also are somewhat irregular, but it seems clear that a high nitrogen supply results in a decided increase in protein. It is evident that the nicotine content tends to follow the nitrogen supply of the plant, while the highest rate of nitrogen fertilization also produced a significant increase in content of nitrates and ammonia. The total nitrogen in the leaf increases as the rate of nitrogen fertilization is increased, and the major increase in percentage content is obtained in the increase in fertilization rate from 40 to 80 pounds per acre.

With respect to nonvolatile organic acids the analytical data indicate a definite increase in citric and malic acids as the rate of nitrogen fertilization is increased, while the oxalic acid values are not materially affected. The results for citric and oxalic acids are believed to be fairly reliable, but those for malic acid probably are too high and no method was available for checking the data for the latter. The figures for content of plant wax are irregular and do not seem to be especially significant. The values for tobacco resins obtained by the empirical procedure of Degrazia do not indicate significant effects of the nitrogen supply with respect to either the content of total resins or the distribution of the several resin fractions. Under the conditions the content of total ash is not much affected by rate of nitrogen fertilization. The contents of potash and phosphoric acid seem to be somewhat reduced by an increased nitrogen supply, while the contents of calcium oxide and magnesia remain approximately constant.

As regards distribution of the nitrogen in the cured leaf (table 36), the insoluble or protein fraction, which constitutes about two thirds of the total, decreases somewhat with increase in nitrogen fertilization. The product grown with a supply of 20 pounds of nitrogen per acre runs relatively low in the soluble fractions determined, for reasons that are not known. There is a general tendency toward increased proportions of the several soluble fractions as the rate of nitrogen fertilization is increased, with the exception of the amino-nitrogen component. In no case, however, is this increase particularly striking.

## INTERPRETATION OF RESULTS AND CONCLUSIONS

### YIELD AND VALUE OF CROP

It is believed that the soil areas employed were sufficiently uniform to leave no doubt as to the significance in yield and value obtained with various quantities and forms of nitrogen, at least when the successive increments of nitrogen used were as much as 20 pounds per acre. (See tables 5, 7, and 10.) Interpretation of the data is somewhat less certain with 10-pound increments of fertilizer nitrogen, although even in this case the results in the main probably are at least approximately correct. With a 10-year combined average yield (table 5) of 614 pounds of leaf and 325 pounds of stalk per acre for the several plots receiving no nitrogen in the fertilizer and without applying corrections for variations in the individual control plots, the increases in the yield of leaf for each pound of nitrogen in the fertilizer in the nitrate of soda series were 13, 13, 11, 9, and 5.5 pounds, respectively, for the 10-, 20-, 30-, 40-, and 80-pound rates of fertilizing. The corresponding increases in yield of stalk were 13, 14, 10, 8.5, and 4.5 pounds. Analysis of the results shows that the effectiveness of the 80-pound rate of nitrogen fertilization was dependent to a considerable extent on the method of application employed. The data as a whole indicate that under the conditions the yield with 40 pounds of nitrogen per acre is not far below the maximum obtainable unless split applications of nitrogen are made, in which case 80 pounds per acre give a decided additional increase.

As regards applicability of the Mitscherlich formula to the yield data, the principal question involved is whether the numerical value of 0.122 which Mitscherlich has assigned to the so-called constant, $c$, holds true under the conditions of these tests. Investigators are sharply divided on the question of whether $c$ really remains constant under all conditions. Mitscherlich and his followers (*18*) have presented extensive data in support of the affirmative side, while a number of investigators have advanced experimental evidence tending to show that the numerical value of $c$ may vary widely under sufficiently diverse conditions. Among the latter may be mentioned particularly Lemmermann, Hasse, and Jessen (*17*) who found that in general the value of $c$ tends to increase as the general environment becomes less favorable for growth, and in this connection in field plot tests with nitrogen as a fertilizer the value of $c$ was found to vary through a wide range, attaining a maximum of 1.03.

Inspection of figure 6 and table 9 shows at once that Mitscherlich's value for $c$ leads to inconsistent and abnormally high values for $A$, the maximum yield obtainable. These values are far in excess of the

maximum yields indicated by the curves representing yields actually obtained at various rates of fertilization. The indicated quantity of the soil's reserve supply of nitrogen, *b*, also appears to be too high. The relative quantities of nitrogen recovered by the crop on the control plots and on those receiving 20 pounds of nitrogen per acre as fertilizer (table 18) indicate a content of 20 to 25 pounds of available nitrogen in the soil. As a necessary consequence of unsatisfactory values for *A* and *b*, the computed yields for various rates of fertilization utterly fail to agree with those actually obtained. It seems clear that Mitscherlich's value for nitrogen is much too low to fit the present data and, in fact, the computations in table 9 show that the numerical value of *c* must be raised to unity or higher in order that the formula may yield results even roughly agreeing with those actually obtained. On the whole, best results are obtained by assigning to *c* a value of about 1.2.

A second difficulty encountered in applying the Mitscherlich equation is the fact that the curves representing the actual yields are not uniform throughout their course as is required by the Mitscherlich formula, but, on the contrary, the lower increments of yield approximate a linear series followed by a rather abrupt decrease in the increments from intermediate rates of fertilization, especially in the case of the stalk yields. For this reason there can be no fixed value for *c* capable of accurately portraying the relationship between the nitrogen supply and the yield for both low and high rates of fertilization. Finally, as shown in figure 7, the proportions of stalk and leaf in the plant are materially influenced by the nitrogen supply and consequently no single formula can give equally satisfactory results for these two organs of the plant. It appears that in the case of the stalk there is no value for *c* in the Mitscherlich formula which will give satisfactory agreement with the yields actually obtained, and this situation applies in a somewhat lesser degree to the yields of leaf and stalk combined.

The data on recovery of fertilizer nitrogen by the crop in 1919, 1925, and 1929 in the nitrate of soda series (table 18) supply one reason for the sharp falling off in the yield increment in passing from the 20- or 30-pound rate to the 40-pound rate of fertilization and for the marked variation in yield from year to year in a given treatment. While recovery of the first 20 pounds of nitrogen was comparatively good (40 to 90 percent), the additional nitrogen recovered from the 40-pound rate of fertilization was surprisingly small. The 40-percent recovery from the first 20 pounds of fertilizer nitrogen and the relatively low yield in 1919 were associated with a rainfall of 11 inches in July and August, the 60-percent recovery and a good yield in 1925 were associated with a rainfall of 6.7 inches in July but only 2.6 inches in August, while in 1919 the 90-percent recovery of nitrogen and the heavy yield were accompanied by a rainfall of only 4.2 inches for the 2 months. It seems very probable that the midsummer rainfall figured prominently in these results. The proportionately higher recovery of nitrogen in 1925 and 1929 than in 1919 from the 80-pound rate of fertilization as compared with the 40-pound rate doubtless was due largely to fractionation of the fertilizer application. With only one exception for the leaf and two for the stalk increasing rates of nitrogen fertilization resulted in progressive increase in percentage content of nitrogen in the plant, showing that the additional nitrogen

absorbed with increasing rates of fertilization becomes progressively less effective in promoting growth. In other words, the decreasing increments of yield with increasing rates of fertilization apparently are due partly to a decrease in the proportion of the fertilizer nitrogen absorbed by the plant and partly to decreased effectiveness of the nitrogen actually absorbed in promoting growth.

The results obtained with the various sources of nitrate and ammonia nitrogen (table 6), on the whole, indicate that under the conditions of the tests these two forms of nitrogen were about equally effective in increasing the crop yield provided due consideration is given to the disturbing effects of other ions contained in the nitrogen compounds or in the soil, more particularly those of magnesium, calcium, chlorine, and sulphur. The somewhat superior results with ammonia nitrate suggest, however, that a combination of ammonia and nitrate nitrogen may be more effective than either form alone. Prianischnikow (*21*) found that under conditions unfavorable to nitrification the relative efficiency of nitrate and ammonia nitrogen cannot be expressed by a fixed coefficient, since it is dependent on a number of factors internal and external to the plant. For example, with a low or a negative hydrogen-ion value and a relatively high concentration of calcium ions, ammonia nitrogen may give superior results, while under reversed conditions of hydrogen- and calcium-ion concentration nitrate nitrogen was more effective. Tiedjens and Robbins (*25*) found that ammonia nitrogen was readily assimilated by several plants which were studied if the medium had a neutral or alkaline reaction, whereas nitrate nitrogen was most efficiently assimilated in a distinctly acid medium. Contrary to conclusions reached by numerous other investigators, these authors found that in the plants studied although ammonia accumulated in considerable quantities in the tissues there was no evidence of toxic effects.

In the case of tobacco, Haas (*12*) has reported development of pathological symptoms from continuing applications of ammonium nitrate solutions to the soil in pot cultures. Beaumont and his associates (*5*) found that in approximately neutral water cultures tobacco was unable to assimilate ammonia nitrogen as readily as nitrate nitrogen and sooner or later toxicity resulted from all ammonium salts used. In field tests (*6*), however, ammonium sulphate gave good results. In the present field tests, in which presumably there was free opportunity for nitrification, no specific symptoms of ammonia toxicity were observed. The reduced yields that were obtained with a combination of the product Ammo-Phos and sulphate of potash prior to the application of dolomitic limestone to the soil (table 7) and the eventual crop failure obtained with a mixture of monoammonium phosphate and nitrate of potash (table 8) have been shown to be due primarily to deficiency of magnesium and calcium in the soil and not to the form of the nitrogen used (fig. 5). These results have been briefly referred to in a previous publication (*11*) in which it was shown by means of supplementary plot tests and chemical analysis of the plant material that there is marked deficiency of both magnesium and calcium in the soil used in the experiments reported in this bulletin. The most striking feature of these particular tests is that omitting both calcium and magnesium from the fertilizer mixture had a much greater effect in suppressing growth of the crop than omission of

nitrogen, and other tests on the same soil show that this effect also is greater than that of omitting phosphoric acid or potash.

The increased yield obtained with ammonium chloride at the lower rates of fertilization as compared with other forms of nitrogen is believed to be due to the stimulating action of the chloride ion, an effect which has been discussed at some length elsewhere (*10*). It has been shown that in favorable concentrations the chloride ion may stimulate growth by enabling the plant to resist drought. Since a high nitrogen supply will be shown to be capable of exercising a similar effect the stimulating action of chlorine may be expected to diminish as the nitrogen supply is increased. These relationships are clearly shown in figure 4.

During the period 1921 to 1929 the average increase in yield from urea somewhat exceeded that from ammonium sulphate at two different rates of application (table 6). However, this series of plots is being continued and in 1930, in which the growing season was extraordinarily dry, ammonium sulphate gave a considerably better yield than urea, although analysis of the plants showed that the recovery of nitrogen from the urea treatments was fully equal to that from the ammonium sulphate. The only sulphur supplied in the basal fertilizer treatment in these tests is that contained in the 80 pounds per acre of sulphate of potash used, and the pale-green color observed in 1930 in both leaves and stems of the plants fertilized with urea indicates that the reduced yield from this treatment under the dry weather conditions probably was due in part to sulphur deficiency. One of the distinctive effects of sulphur deficiency in the soil under normal weather conditions is delayed growth in the early stages of development and it is believed that the hastening effect of ammonium sulphate on date of flowering shown in table 16 was due at least in part to the additional sulphur supplied. There is definite evidence, therefore, that in considering relative fertilizing values of the various synthetic forms of nitrogen on soils of the type here used due consideration must be given to the supply of magnesium, calcium, chlorine, and sulphur made available to the plant.

As regards the effect of the nitrogen supply on the commercial value of the cured tobacco, it should be understood that the data and discussion on pages 22 to 24 relate primarily to Maryland tobacco and do not necessarily apply to other commercial types of leaf. For the Maryland type, best results as to acre value and price per pound of leaf were obtained with 20 to 40 pounds of nitrogen per acre. For best results with respect to quality of product the nitrogen requirements of the various types of tobacco differ materially as regards both the quantity and the form of the nitrogen. It is probable that under comparable conditions the nitrogen requirements of burley tobacco would be somewhat greater than those of Maryland tobacco, while those of the flue-cured type would be only slightly less. On the other hand, the cigar types, especially the binder and wrapper grades, require for best results much larger quantities of nitrogen and this fact, together with the light character of the soils most used in growing the binder and wrapper grades, tends to complicate the question of best forms or sources of the fertilizer nitrogen. Some of the reasons for these contrasts in nitrogen requirements of the different types are brought out in later paragraphs.

### GROWTH RELATIONS AND LEAF CHARACTERISTICS

The rate of growth as measured by increase in height of the plant is markedly affected by the amount of the nitrogen supply, and under the conditions of the test the form of the nitrogen also appears to be of some significance (table 13, fig. 8). Although more or less in evidence in most of the treatments, the familiar sigmoid form of growth curve is best developed with the slow rate of growth which occurs on the control plots receiving no nitrogen in the fertilizer. While the heaviest rate of nitrogen fertilization, 80 pounds per acre, produced a somewhat lower average rate of growth than moderate rates of fertilization, there was no pronounced change in form of the growth curve. The most rapid average increase in size of leaf was produced by the highest rate of nitrogen fertilization. The low rate of growth produced by a deficient nitrogen supply was accompanied by a marked delay in flowering (table 16), and the highest growth rate, which was induced by a moderate rate of nitrogen fertilization, also was associated with earliest flowering.

As regards the effects of the nitrogen supply on comparative development of the principal organs of the plant, it appears that under the conditions of the test the relative growth of the root was not greatly affected, while the development of stem and leaf was decidedly influenced. Nitrogen deficiency materially reduced the proportion by weight of stalk to leaf in the plant, and a high nitrogen supply as compared with a moderate supply also tended to reduce the relative weight of stalk (fig. 7).

From a practical standpoint, the most important effects of the nitrogen supply on development pertain to characteristics of the leaf. The total number of leaves produced by the plant is only slightly influenced by the rate of nitrogen fertilization except that the low growth rate and delayed flowering caused by a markedly deficient nitrogen supply apparently favor a moderate increase in number of leaves produced (table 13). In the case of Maryland tobacco it has been repeatedly observed that various conditions causing delayed growth commonly result in increased number of leaves developed by the plant. The effects of nitrogen deficiency in increasing the number of leaves produced therefore can hardly be considered as specific. The ratio of midrib to lamina in the leaf is of some practical importance. The effect of the nitrogen supply on this ratio was found to be much the same as that on the ratio of stem to leaf in the plant. A deficient nitrogen supply produces a relatively low percentage by weight of midrib, as does also a high supply of nitrogen, while a moderate quantity of nitrogen increases the proportion of midrib to lamina.

The data summarized in tables 14 and 15 show that the effects of an increased supply of fertilizer nitrogen in producing a decidedly broader and larger leaf are coupled with a definite decrease in weight per unit of area, and similar relations are well shown by the data contained in tables 20 and 32. Not only is the increase in yield that is obtained with an increase in the nitrogen supply due to the production of a larger leaf, but the gain in size is even greater than the gain in weight. The reduced weight per unit of area resulting from a high nitrogen supply apparently is due at least in part to a decrease in thickness of the leaf, though it is possible that a less dense type of structure of the tissues also is involved. The data in table 15 indicate

that the average specific gravity of the solids of the leaf is not greatly affected by the amount of the nitrogen supply. The action of nitrogen as a fertilizer on the size, shape, weight per unit area, and thickness of the leaf is of considerable practical importance in relation to the fertilizer requirements of the different commercial types of tobacco as well as being of interest to the plant physiologist. These effects indicate that a liberal supply of nitrogen is desirable when it is sought to produce a broad, thin, light-bodied leaf such as is required for use as cigar wrapper or binder. In this connection it is interesting to note that as much as 200 pounds of nitrogen per acre is commonly used in growing these types of leaf.

The effects of the nitrogen supply on the color and luster of the leaf are of practical importance since the shade, the evenness, and the brilliancy of the color may largely determine the commercial value of the cured product. It appears that when the abnormally pale yellowish-green color characteristic of nitrogen hunger is seen in the plant in the field the cured leaf is likely to be uneven in color and markedly deficient in luster, producing mainly the inferior so-called "dull" grade of product. With a nitrogen supply just sufficient to prevent definite deficiency symptoms there is likelihood of premature ripening and drying or firing of the lower leaves. With a moderate additional increase in the supply of nitrogen a cured leaf of light reddish-brown color and bright luster may be expected. Under the conditions of the test, best results for the Maryland type of tobacco were obtained with 20 to 40 pounds of nitrogen per acre. Heavier rates of fertilization yielded a cured leaf with purer brown or slightly greenish-brown color, with good luster, a result more desirable in cigar leaf.

A thin, light-bodied leaf usually has better burning qualities than a thick, heavy-bodied, close-textured leaf, and since a high nitrogen supply tends to produce the former type its adverse action on combustibility (table 17) probably is due to its effects on the chemical composition rather than the structure of the leaf tissue. It was suggested long ago (*19*) that proteins and related complex compounds of nitrogen tend to injure the burning qualities of tobacco because of the fact that relatively they are difficultly combustible. The results of the present tests are in accord with this theory, for it is shown that an increase in the fertilizer supply of nitrogen results in an increased content of protein and its derivatives in the leaf.

#### INTERNAL PROCESSES OF NUTRITION AND METABOLISM

In general, the results obtained with material from the no-nitrogen treatment are regarded as representing nutrition conditions of moderately severe nitrogen deficiency, those from the 20- and 40-pound rates of fertilization conditions of a medium or balanced nitrogen supply, and those from the 80-pound rate conditions of a high and slightly excessive supply of nitrogen under the conditions of the tests. Broadly speaking, the later stages of growth and the early phases of progressive senescence immediately following, which constitute the so-called ripening period of the lower and middle leaves of the plant, involve predominantly katabolic processes that are closely associated with marked translocation of nutritive materials to the upper parts of the plant. Smirnow and his associates (*24*) have made a comprehensive study of the general nature and results of these processes.

The present biochemical and physiological studies deal chiefly with the effects of the nitrogen supply on the course of these metabolic processes in the fresh leaf prior to harvest and their ultimate effects on the characteristics of the cured leaf.

One of the outstanding physiological effects of the nitrogen supply is that on the water content of the leaf tissues and associated growth phenomena. The data in tables 20, 24, 26, and 32 show that an increased supply of nitrogen materially increases the water content, and the resultant increase in turgidity apparently produces important results in the development of the leaf. It has been pointed out that an abundant nitrogen supply produces a decidedly larger and broader but thinner leaf weighing less per unit of area than is obtained with a low supply of nitrogen. Aside from the mode of action of the nitrogen in reducing or overcoming transpiration losses, it is evident that the effects on the morphology of the leaf are essentially those produced by various other factors which operate to maintain increased turgidity, such as reduced illumination, increased atmospheric humidity, or increased soil moisture. For example, Hasselbring (*13*) who made a careful analysis of the effects of partial shade on the leaves of tobacco found that their water content was definitely increased, and in association with this effect the leaves were increased in size but weighed less per unit of area. The osmotic concentration of the cell sap seems not to contribute materially to the nitrogen effect on water relations and associated growth phenomena in the leaf (table 22). It appears likely that an increase in content of hydrophilic colloids resulting from an increased intake and assimilation of nitrogen is an important factor, but no studies were undertaken in this direction.

The effect of the nitrogen supply on water content was found to extend to the hygroscopic properties of the cured leaf (table 21). Here again the effect is of considerable importance from a practical standpoint. The capacity of the cured leaf to attract and retain a sufficient quantity of moisture to render it pliable and more or less elastic is of special importance in cigar-wrapper and binder types. The effect of an increased nitrogen supply in this direction suggests that the nitrogenous component of the leaf contributes directly to its hygroscopicity. It appears that the process of curing, at least when the leaves are detached from the stalk in harvesting, tends to render the product more hygroscopic. This result probably is due in part to loss of relatively nonhygroscopic material and in part to accumulation of hygroscopic products of protein decomposition during the curing process. On the other hand, the tendency of the leaf to attract moisture decreases with increase in age, so that during the ripening period the leaf becomes less hygroscopic.

Observations on the active acidity of the cell sap of the leaf (table 23) show that as the ripening or ageing of the green leaf advances there is a definite decrease in the pH value. Since the lower leaves are the first to reach maturity their active acidity usually will be greater in later stages of development of the plant than that of leaves higher up on the stalk. The delayed growth and maturation resulting from a deficient supply of nitrogen is clearly reflected in the slow rate at which the active acidity of the leaf sap increased after the plants had been topped. On the whole, the pH value seemed to fall most rapidly in the plants receiving 40 pounds of nitrogen per acre. Under the conditions of the test the pH value of the immature

leaf was approximately 6.35, or higher, and this value decreased to as low as 5.60 in the fully ripe leaf. The data secured on the content of malic, citric, and oxalic acids (table 24) are not adequate for obtaining a clear picture of the changes taking place during the ripening period in relation to the nitrogen supply. When these data are considered in connection with those for cured leaf (table 35), however, the conclusion seems justified that as the leaf approaches full maturity an increased supply of nitrogen tends to increase the content of citric acid, and the indications are that this relation holds true also for malic acid.

In attempting to obtain information as to the internal mechanism through which variations in the nitrogen supply affect the processes of nutrition and growth the nitrogen metabolism of the plant naturally is of special importance. The fact that during a period of 7 weeks immediately preceding the flowering stage there was a marked progressive decrease in content of total nitrogen and protein nitrogen in the lower leaves of the plant (table 20) might be taken to indicate a very active physiological translocation of the nitrogen from these leaves. For the entire period the decrease in total nitrogen per unit of area averaged nearly 40 percent of that originally present, and the decrease in protein nitrogen was about 58 percent of the original content. Despite these large decreases in total and protein nitrogen there was comparatively little change in content of nitrate, ammonia, nicotine, amino, and amide nitrogen or in the undetermined fraction, thus suggesting that the protein nitrogen undergoes translocation almost as rapidly as it is transformed into soluble forms. However, the leaves increased their area by 25 to 50 percent during the period of observation, and the data in table 20 show that the greater portion of the nitrogen disappearing from the older tissues did not actually depart from the leaves but was utilized in increasing the leaf area. Incidentally these studies show the danger of employing analytical data on a basis of either the percentage content or the content per unit of area in drawing conclusions involving such processes as physiological translocation. In this instance it is essential that the entire area or the mass of the leaf be taken into account.

In association with the slow growth and visible symptoms of nitrogen hunger seen in the plants which received no nitrogen in the fertilizer, the leaf was distinctly low in content per unit of area and on a percentage basis in total, protein, nicotine, nitrate, amino, and amide nitrogen throughout the 7 weeks preceding the flowering stage. While the addition of 20 pounds of nitrogen per acre to the soil produced a decided increase in the content of total and protein nitrogen in the leaf, further additions to the soil showed very little effect on the concentration of nitrogen in the leaf except in the late stages of development (table 20 and fig. 9). On the other hand, in the flowering stage of the plant and subsequently, the content of total nitrogen and protein nitrogen in the leaf increased with each increase in the rate of nitrogen fertilization (tables 20, 24, and 25).

To interpret correctly the foregoing results it is necessary to take into consideration the relative increase in size of the leaf and its total nitrogen content under the different treatments (table 20). The quantity of nitrogen entering the individual leaf increased with increase in the quantity made available in the soil. The addition of 20 pounds of fertilizer nitrogen to the soil's reserve supply effectively

overcame deficiency symptoms in the leaf, and the increased nitrogen content per unit of leaf area that resulted is explainable perhaps on the assumption that the additional nitrogen thus supplied was largely needed to meet immediate nutritional requirements, leaving only a relatively small portion available for expansion of the leaf surface. Further additions to the nitrogen income of the leaf, on the other hand, were chiefly utilized in increasing its surface without further increasing the content of nitrogen per unit of area. After the immediate nutrition requirements had been met the effectiveness of additional nitrogen in promoting leaf expansion increased as the nitrogen supply was increased, as evidenced by a reduction in thickness of the leaf and even a reduction in the content of nitrogen per unit of area. The changes in content of soluble protein in the expressed sap of the leaf taking place during the ripening or ageing process, as measured by the Stutzer method, and the effects of the nitrogen supply on this value tend to follow those applying to nonsoluble protein.

At all rates of fertilization a portion of the nitrogen of the leaf (10 to 20 percent) was returned to the stem of the plant even during the period of rapid growth. It is significant that the quantity thus surrendered was least in the leaves that received the most liberal supply, indicating that a relatively high nitrogen supply tends to cause the leaf to retain its vegetative vigor longer. The very low nitrate values obtained indicate that even at the highest rate of fertilization here employed the nitrogen supply was not in excess of that which could be assimilated. However, where very large amounts of nitrogen are made available to the plant, nitrates may be stored in the leaf in important quantities, as demonstrated by Vickery and Pucher (*26*) for Connecticut cigar leaf. Whether under these conditions nitrogen metabolism would depart from the course traced in the present experiments cannot be stated. Increase in the rate of nitrogen fertilization had but little effect in increasing the nicotine content of the leaf during the period of most active growth and synthesis of protein, but this effect became more pronounced as the flowering stage was reached. Subsequently there was only a slow increase in nicotine content with a deficient or a low supply of nitrogen, but as the rate of nitrogen fertilization was increased there was an increase in the rate of nicotine accumulation in the leaf (table 24). Consequently, as the leaves reached maturity those that had received the highest supply of nitrogen were decidedly highest in nicotine.

The above results bearing on nitrogen metabolism apply to conditions of high topping. Data presented in table 30 show that in the lower leaves metabolism is profoundly affected by very low topping. Reduction in the transfer of mobile materials from the leaves into the stem as a result of removing approximately the upper half of the plant in the topping operation largely accounts for the decided thickening of the lower leaves even though, under the prevailing conditions of drought, there was not much increase in their size. In these circumstances there was a marked increase in content of total nitrogen per unit of leaf area, accompanied by a somewhat less pronounced gain in protein nitrogen which is in sharp contrast with results under conditions of high topping. Perhaps the outstanding effect of the low topping on nitrogen metabolism was the remarkable increase in nicotine content amounting to nearly 200 percent for a period of 25 to 30 days following the topping.

The observations on carbohydrate relations in the leaf recorded in tables 25 and 27 show that in general the effect of an increased supply of fertilizer nitrogen on the content of starch in the leaf both during the period of active growth and in the later stages of development is the reverse of that on the content of nitrogen, for with a very low nitrogen supply the starch content of the leaf is high, while only a moderate increase in the supply of nitrogen materially lowers the starch content. In other words, there is a complementary relationship between the nitrogen content and the starch content in the leaf. This relationship apparently does not apply to the content of sugar which occurs in the leaf chiefly in the form of monosaccharide. While the nitrogen content tends to constantly decrease during the growth and development of the leaf until a minimum is reached during the ripening or aging period, the content of carbohydrate decreases only temporarily as the plant attains the flowering stage, after which it tends to increase again.

Observations on oxidizing enzymes indicate that they attain their maximum activity at about the time the leaf reaches its greatest vegetative activity. A high nitrogen supply, which increases and prolongs vegetative activity, also increases the catalase activity of the leaf and tends to defer the stage in its life history at which decrease from the maximum catalase activity begins (table 28). Again, low topping of the plants, which increases the nitrogen content and stimulates vegetative vigor, likewise results in increased catalase activity (table 31). Data obtained on peroxidase activity (table 29) show essentially the same relationships that apply to catalase.

Although the nitrogen supply has been found materially to influence metabolic processes in the leaf and its composition in the fresh mature state, the data in table 32 indicate that in the curing process the loss in total dry matter is not greatly affected. The effect of the nitrogen supply on the weight per unit of area of the cured leaf was about the same as that on the leaf in the fresh state. There was an appreciable increase in the content of so-called "tobacco resin" during the curing, but the practical significance of this group of constituents is not definitely known. The results obtained in following the catalase relations through the curing process are of considerable interest. It is known that the greater portion of the loss in dry matter occurs in the first few days of the curing, and it was found that during this period there may be an appreciable increase in catalase activity. In later stages, however, catalase activity decreases sharply so that at the end of the curing the leaf retains but a small fraction of its initial activity. Although, in line with results previously discussed, leaves grown with a high nitrogen supply showed a relatively high catalase activity in the early stages of curing, at the end of the process the activity of such leaves tended to approach that of leaves grown with a low supply of nitrogen (table 33). There was a small decrease in the peroxidase number during the curing. As in the fresh leaf, the peroxidase value in the cured leaf was increased by increase in the rate of nitrogen fertilization (table 34).

In contrast with the result in normal curing, rapid drying at ordinary temperatures preserves in large part the catalase activity of the fresh leaf. The fact that if the leaf is exposed to chloroform vapor before the drying most of this activity is rapidly lost, may well be due to the action of the chloroform as a protoplasmic poison,

thus permitting diffusion of the cell sap and rapid contact between the catalase and the constituents of the cell sap with which it reacts.

### CHEMICAL COMPOSITION OF CURED LEAF

In the cured state the Maryland type of leaf is characterized mainly by its peculiar dry, light, chaffy nature and its mildness, and it normally possesses good burning qualities. The better grades possess a light reddish-brown color. These characteristics of Maryland tobacco are explainable in part on the basis of the chemical composition of the leaf as disclosed in tables 35 and 36. It is exceptionally high in both cellulose and pectins, constituents of the cell wall, the combined content of these two groups of carbohydrate accounting for about a third of the chemical make-up of the leaf. Most other domestic types of leaf usually contain less than 25 percent of these constituents. The high content of cell-wall material undoubtedly contributes to the dry character and the free combustibility of the Maryland type. The content of the more plastic forms of carbohydrate, starch, and sugars is comparatively low in the cured leaf. Cigar-leaf types in the cured state normally are quite low in starch and sugar and when cured under favorable conditions more commonly are practically free of these constituents. Flue-cured tobacco, on the other hand, contains considerable quantities of starch and is very high in sugar, the better grades usually containing 10 to 20 percent. The mildness of Maryland tobacco is accounted for by its low nicotine content (less than 2 percent), most other types usually containing 2.5 to 5 percent.

The nitrogen content of Maryland tobacco is low, averaging perhaps 2 to 2.5 percent, in line with the data shown in table 35. This average probably is about the same as, or only slightly higher than, the average for the flue-cured type of tobacco. However, the cigar-leaf types (*1*, *4*, *16*), burley, and the fire-cured types (*22*) usually contain 3 to 5 percent of nitrogen. These types frequently though not always contain considerable quantities of nitrate nitrogen, while the flue-cured and Maryland types are characteristically low in nitrates. Maryland tobacco contains less total ash and decidedly less potash than some of the cigar-leaf types but does not differ greatly in these respects from flue-cured leaf.

The nitrogen supply apparently is not an important factor in the leaf content of cellulose and pectin, but it is evident that an increase in the supply of this element tends to decrease the content of starch and sugar. Increase in the rate of nitrogen fertilization produces a decided increase in total nitrogen and in all of the nitrogen fractions determined. Addition of 80 pounds of nitrogen per acre to the small supply already present in the soil increased the protein nitrogen of the leaf more than 50 percent and the nicotine nitrogen more than 100 percent. In view of these effects on the composition and those on the color of the leaf it can be seen that only a moderate supply of nitrogen will tend to produce cured leaf of normal characteristics for the Maryland and the flue-cured types, while a high nitrogen supply will favor production of leaf resembling the cigar-wrapper and binder types. To the extent that the tobacco resins may be a factor in providing the aroma of cured tobacco, the data obtained would indicate that this property is not dependent primarily on the quantity of nitrogen made available to the plant. The ash content, which

is of considerable importance in relation to combustibility and other characteristics of the leaf, seems not to be much affected by the rate of nitrogen fertilization at least under the conditions of these tests. The Maryland cigarette type of leaf, after curing, lacks capacity to undergo the active fermentation characteristic of cigar types. The former is a low-nitrogen type and the latter are high-nitrogen products, and since a high-nitrogen content is associated with high catalase and peroxidase activity it seems likely that the content of the oxidizing enzymes is an important factor in the fermentative capacity.

## SUMMARY

Field-plot tests have been conducted for periods of 4 to 11 years on fine sandy loam and on loamy sand types of soil of the Collington series in southern Maryland to ascertain the quantity of nitrogen required for best results with the southern Maryland type of tobacco and to compare the fertilizing value of the older inorganic forms of nitrogen and some of the new synthetic products. As another major feature of the work, the tobacco grown on these plots was utilized for conducting fairly extensive physiological and biochemical observations on the effects of variation in the nitrogen supply on growth and developmental relations and associated internal processes of nutrition and metabolism. The sources and quantities per acre of nitrogen employed in the tests were: Nitrate of soda, supplying 10, 20, 30, 40, and 80 pounds; ammonium sulphate and ammonium chloride, supplying 20, 40, and 80 pounds; ammonium nitrate, cyanamide, urea, urea phosphate and Ammo-Phos, supplying 20 and 40 pounds; a combination of nitrate of potash and monoammonium phosphate, supplying 40 pounds. The basal fertilizer used in most instances furnished 60 pounds of phosphoric acid and 40 pounds of potash per acre.

With respect to crop yields, the 80-pound rate of nitrogen fertilization proved to be excessive when all of the nitrogen was applied in the row prior to transplanting, and it produced no significant increase over the 40-pound rate. However, a decidedly larger yield was obtained with the 80-pound rate when one half of the nitrogen was applied after transplanting the crop. Taking average results for all sources except cyanamide, 20 pounds of nitrogen per acre gave an increase in yield of about 300 pounds of leaf tobacco over the yield of approximately 600 pounds on the control plots. The corresponding average increase in yield of leaf from 40 pounds of nitrogen per acre was about 400 pounds. With nitrate of soda as the source, 40 pounds of nitrogen per acre gave only slightly better results than 30 pounds.

The results obtained with the various sources of nitrate and ammonia nitrogen show that under the conditions of the tests these two forms of nitrogen were about equally effective in increasing the crop yield when proper consideration is given the effects of other ions contained in the nitrogen compounds or in the soil. Ammonium sulphate and nitrate of soda were equally effective while ammonium nitrate, supplying both ammonia and nitrate nitrogen, gave somewhat superior results. Ammonium chloride gave relatively high yields because of the stimulating effect of the chloride ion. The soil used in the tests was decidedly deficient in magnesium and calcium and in dry seasons was deficient also in available sulphur. For these

reasons very poor results were obtained with the combination of nitrate of potash and monoammonium phosphate unless the elements in question were added to the soil and somewhat similar results were observed with the product Ammo-Phos. Urea gave better results than ammonium sulphate except when the sulphur supply was a limiting factor. Cyanamide gave fairly good results when used in limited quantities.

Attempts to apply the Mitscherlich law to the yield data for leaf and stalk and the two combined gave very unsatisfactory results. The numerical value of 0.122 assigned by Mitscherlich to the proportionality factor, *c*, of his equation for the fertilizer element, nitrogen, proved to be far too low to fit the yields actually obtained at various rates of fertilization. Although Mitscherlich considers that the validity of his law rests on the constancy of the numerical value of *c* under all conditions, it was found necessary to increase this value approximately tenfold (to 1.2) in order to obtain yield data for the leaf agreeing approximately with the yields actually obtained. The increments of yield actually obtained at lower rates of fertilization tend to form a linear series, but at intermediate rates of fertilization a rather abrupt decline in yield increments appears in the yield curves, especially in the curve for yields of stalk. For this reason the Mitscherlich type of curve cannot accurately portray the results at both high and low rates of fertilization. Again, the relative yields of leaf and stalk are modified by the amount of the nitrogen supply, so that no single formula of this type will satisfactorily fit the data for both leaf and stalk.

The best average grade of leaf for the southern Maryland type was obtained with 20 or 40 pounds of nitrogen per acre and in the nitrate of soda series 30 pounds gave slightly better results than 40 pounds. Considering both yield and quality of product, the most profitable returns were obtained with 30 to 40 pounds of nitrogen per acre. When no nitrogen was used in the fertilizer the so-called "dull" grades of leaf, lacking in luster, were chiefly obtained. Ammonium chloride gave a poor quality of leaf as did cyanamide at the higher rate of application, but there were no marked differences in the effects of other forms of nitrogen. The ammonium chloride had a decidedly unfavorable effect on the combustibility of the leaf.

The ratio by weight of leaf to stalk in the plant was relatively high with a very low as well as with a high supply of fertilizer nitrogen as compared with results obtained with a moderate nitrogen supply. The same relationships apply to the ratio of lamina to midrib in the leaf. Through its effect on water relations in the plant, the chloride ion of ammonium chloride produced a high ratio of leaf to stalk. The nitrogen supply apparently did not greatly affect the ratio by weight of root to stalk and leaf.

The growth rate, as measured by increase in height, was slow when the nitrogen supply was deficient, but a moderate rather than a high supply produced the most rapid increase in height. The sigmoid type of growth curve was best developed in association with the slow rate of growth obtained under conditions of nitrogen deficiency. A high nitrogen supply produced the most rapid increase in size of leaf. Early flowering and early ripening of the leaves were favored by a moderate supply of nitrogen.

The effects on leaf development obtained by varying the amount of the nitrogen supply are of considerable importance. The effect on the number of leaves produced was slight, but an increased supply of fertilizer nitrogen decidedly increased the area and the ratio of width to length of the individual leaf, while the dry weight per unit of area and the thickness of the leaf were reduced materially.

Increase in the supply of nitrogen reduced the combustibility of the leaf, probably because of the effect in increasing the content of protein or its derivatives.

With nitrate of soda as the source of the fertilizer nitrogen, the quantity recovered by the crop ranged from 40 to 90 percent when only 20 pounds per acre were applied to the soil, the recovery depending to a considerable extent on the midsummer rainfall. The additional nitrogen recovered by the crop from the 40-pound rate of fertilization was small. The percentage content of nitrogen in the stalk slightly exceeded that in the leaf, while in the leaf the content of the midrib was only a little more than one half that of the web. There was a progressive increase in nitrogen content from the ground leaf upward to the top leaf of the plant. The most characteristic symptom of nitrogen deficiency was a pale yellowish-green color of the lower leaves of the plant, and this symptom usually appeared when the nitrogen content of the leaf fell below about 1.5 percent.

One of the outstanding effects of an increased supply of nitrogen was markedly to increase the water content of the leaf throughout its development. This increase seems to be an important factor in the increase in area and decrease in weight per unit of area of the leaf produced by the increase in nitrogen supply. These effects are much the same as those produced by partial shade and other factors favoring increased content of water in the leaf. A high nitrogen supply also increased the power of the cured leaf to absorb moisture.

The active acidity of the leaf was affected by the nitrogen supply only in so far as the rate of maturation was modified, the general tendency being for the pH value of the sap to decrease with advance of the ripening or ageing. A high content of nitrogen tended to increase the content of nonvolatile organic acids in the mature leaf. The starch content was found to stand in an inverse relation to the nitrogen supply and the nitrogen content of the leaf, but the content of sugars was little affected by the supply of fertilizer nitrogen. Catalase and peroxidase activity appear to stand in direct relation to vegetative activity in the leaf and were found to reach their maximum in the later stages of leaf growth and thereafter gradually to decline. The content of catalase and peroxidase was considerably increased by increase in the rate of nitrogen fertilization.

During the period of growth preceding the flowering stage of the plant, the content of total and protein nitrogen in the lower leaves, on the basis of equal area, was materially increased only by the first 20 pounds per acre of fertilizer nitrogen, and the additional nitrogen absorbed as a result of heavier fertilization was mostly used in increasing the leaf area. Likewise, the progressive decrease per unit of area in total and in protein nitrogen observed during the growth period at all rates of nitrogen fertilization was due chiefly to transfer of nitrogen from the older tissues to the growing portions of the individual leaf. During this period the content of nicotine, nitrate, ammonia,

and amide nitrogen was relatively low and with the exception of the first 20 pounds of fertilizer nitrogen was not materially increased by increase in the nitrogen supply. On the other hand, in the mature leaf the total, protein, and nicotine nitrogen contents increased with each increase in rate of nitrogen fertilization. In contrast with results in high topping of the plants, with low topping there was, during the ripening period of the leaf, a large increase in total and protein nitrogen and a very large increase in nicotine nitrogen. The studies in nitrogen metabolism developed the fact that, in following the nitrogen exchange of the leaf during growth, neither the values based on unit area nor those on a percentage basis are adequate, it being necessary to take into account the total area or mass of the individual leaf.

The plant's supply of nitrogen did not greatly affect the loss in total dry matter of the leaf in the curing process, which amounted to 21 to 22 percent. In the later stages of curing there were in all cases marked losses in catalase and smaller losses in peroxidase activity.

In the cured leaf the content of total protein, nicotine, and nitrate nitrogen was decidedly increased, the content of other forms of nitrogen and of nonvolatile organic acids were increased to a lesser extent, and the contents of starch and sugars were reduced by an augmented supply of fertilizer nitrogen. There was no decided effect of nitrogen on the contents of cellulose and pectin, the tobacco resins, and total ash. The amount of the nitrogen supply is one of the important factors determining not only the grade or quality but also the type of the leaf produced, that is, its adaptability to specific manufacturing purposes.

Maryland tobacco, which is primarily a cigarette type, is characterized by a high content of cellulose and pectin to which are due to a large extent its outstandingly light weight and dry character and in part, at least, its good burning qualities. It is also characterized by a low content of nicotine, to which it owes its mildness. These characteristics are best developed with a moderate nitrogen supply.

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# EFFECT OF QUANTITY AND KINDS OF FEED ON ECONOMY OF GAINS AND BODY COMPOSITION OF HOGS[1]

By N. R. ELLIS, *chemist*, and J. H. ZELLER, *associate animal husbandman, Animal Husbandry Division, Bureau of Animal Industry*

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## INTRODUCTION

Efficiency in the feeding of domestic animals involves not only the proper selection and combination of feeds and method of feeding, but also the proper daily allowance. In the case of dairy cattle, much attention has been given to the choice of feeding standards which provide the optimum level of protein, total energy, and other nutrient factors for efficient milk production. The profitable performance of animals raised for meat, such as hogs and cattle, depends in great measure on both the economy of live-weight increase and the quality of the meat.

In the case of hogs, the effect of variations in the level of feed intake on the efficiency of conversion of feed into body tissue and on the composition of the body has received little attention in comparison with that given to the many other feeding experiments, conducted during recent years, on the influence of the diet on rate of growth. Perhaps the main cause for this lack of attention has been the general

[1] This work was first undertaken as a part of the project, cooperative soft-pork investigations, which has been combined with the national project, cooperative meat investigations. The Bureaus of Animal Industry, Agricultural Economics, and Home Economics of the U.S. Department of Agriculture, and the agricultural experiment stations of 28 States have been or are now participating in the national project. The following representatives assisted in conducting the work: In firmness grading of carcasses, O. G. Hankins, Bureau of Animal Industry, and E. H. Hostetler, North Carolina Agricultural Experiment Station; in slaughtering and physical composition, K. F. Warner and R. L. Hiner, Bureau of Animal Industry; in chemical composition, H. E. McClure (resigned), W. O. Poole (resigned), R. W. Riemenschneider, J. M. Spadola, and W. R. Kauffman, Bureau of Animal Industry; in cooking tests, Lucy M. Alexander, Bureau of Home Economics; in statistical analyses and computations of carcass composition, Mrs. E. V. Steely, Bureau of Animal Industry, and a number of representatives of the Bureaus of Agricultural Economics, Home Economics, and Animal Industry for services on the palatability-of-meats committee. Acknowledgment is made to E. W. Sheets, Paul E. Howe, E. Z. Russell, S. S. Buckley (deceased), and O. G. Hankins for suggestions and advice.

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assumption that a maximum rate of gain was of greatest importance. Economic reasons—for example, the desire to reduce the labor cost or to produce hogs for the early and top-price market—have governed feeding practices, in which rapidity of gains has been uppermost. In the study of the correction of nutritional deficiencies in hog rations, the increase in the growth rate along with greater feed utilization has been highly significant. It has been only natural to consider that there is a direct relationship between increase in growth and efficiency of feed utilization. Improvements in the nutritive values of feed combinations usually have been accompanied by increase in palatability and hence increased consumption.

The building of adipose tissue is a relatively more expensive process in terms of feed requirements than is the building of protein tissue. In addition, the changing market demands for meat have tended towards less fat in the pork cuts. Changes in hog types and the use of efficient protein, vitamin, and mineral supplements with corn in the hog ration have been an aid in meeting the demand for leaner meat. The readiness with which the hog stores fat mitigates against any pronounced decrease in fat storage as long as the hog remains on an ad libitum basis of feeding. Experiments [2] have shown that the nutritive ratio of a diet could be varied from 1:2 to 1:10 without effect on the fat content of hogs slaughtered at a weight of approximately 200 pounds. Restriction of the feed consumption offers a possible means of lessening the quantity of fat stored and thereby increasing the yield of lean meat in the carcass. Such a practice in feeding immediately raises the questions of economy of gains, rate of gain, and quality of meat as affected by age and fatness of hogs.

The purpose of these investigations was to determine the effect of different levels of feed intake by hogs (1) on the efficiency of converting feed into gain in weight, (2) on the physical and chemical composition of the meat and carcass, and (3) on the firmness, palatability, and other quality factors of the meat. Data are presented on three basal feeds, namely peanuts, corn, and wheat. Comparisons of feeding levels were made with the same diet in each experiment.

Among the questions involved in a study of this kind is that of experimental feeding methods. The usual feeding comparison, whether by the paired method or otherwise, does not take into account the possible differences in the response of hogs to different diets fed at equal and graduated levels or at free choice and variable levels. The question relative to the composition of the meat is largely one of fatness. The possible implications of control or limitation of the fat content of the carcass involve the changes in the yields of the lean and the fat cuts.

## PREVIOUS INVESTIGATIONS

Interest in the effect of limited feeding was first aroused by the results from hog-feeding experiments [2] in which a study was made of the effect of retarded growth, through the lowering of the feed intake, on subsequent growth on full feed and on the firmness of the carcass. One lot of hogs was on a restricted ration during the first period and was self-fed during the second period. The other lot was full fed during the entire period. The former lot made so economical a utilization of feed during the second period that the cost of feeding

[2] Unpublished data.

and quantity of feed consumed were practically the same for the two lots during the entire experiment, even though an unbalanced ration of corn and mineral mixture was used during the restricted period. The results showed that limitation of feed did not produce any apparent permanent impairment to the well-being of the animal body as evidenced by the subsequent growth when the animals were changed to self-feeding.

Interest in the subject was further stimulated by observations on the growth of pigs on peanut rations (*7, 8, 9*).[3] Not only do hogs make greater gain in weight on a given quantity of a ration high in peanuts as compared with one high in corn, but they frequently show excessive fatness after periods of 2 months or more on a peanut ration, owing largely to the high oil content of peanuts. The suggestion was advanced that limitation of the feed intake might reduce the storage of oily fat without undue sacrifice in the rate of gain or the feed requirements per unit gain.

Comparisons of different levels of feeding have been conducted with hogs in connection with studies on the utilization of forage crops. In the usual case the animals have been given free access to a forage crop and have been hand fed at various levels ranging from approximately 4 pounds to 1 pound of feed per day per 100 pounds of live weight. Results of many feeding trials have shown a material saving of concentrate feeds at the lower feeding levels. However, it has been found that limited feeding of a concentrate ration with access to forage or hay may not lower the total feed consumption in all cases. Robison (*18*) compared the feed requirements of fall pigs on a full feed of corn and tankage with their requirements on a limited feed of corn and tankage, with access to alfalfa hay in both types of feeding. Although in the limited feeding the requirements for concentrates were reduced, the extra quantity of alfalfa hay consumed raised the total quantity of dry matter above that consumed by the full-fed groups.

The adoption of the self-feeder in place of hand feeding in swine-husbandry practice was due in great measure to the saving in labor and feed. The advantages of the self-feeder have been described by Henry and Morrison (*10*). Their summary of results of self-feeding in comparison with hand feeding pigs in dry lot (*10, p. 614*) shows a higher daily feed consumption for the self-fed pigs. Further, they state that this "is due to the fact that self-fed pigs help themselves many times a day and even during the night, thus being full fed at all times." At another point the same authors have expressed the prevailing opinion relative to full feeding in these words:

> When pigs are fed about all they will eat either by means of a self feeder or by hand feeding, they will consume less feed for each 100 pounds' gain up to market weights and therefore the gains will be cheaper than if they had been fed less grain.

Armsby (*1*), in discussing the production values of feedstuffs, states:

> It has been tacitly assumed that both the losses of chemical energy in the excreta and the increment of heat production consequent upon feed consumption are proportional to the quantity of feed ingested, that is, that the net energy values per unit of feed are substantially unaffected by the amount consumed or by the plane of nutrition of the animals.

Later in the discussion of this matter he mentions that heavy feeding may lower the digestibility of mixed rations, but that on the whole

[3] Italic numbers in parentheses refer to Literature Cited, p. 30.

"the net energy values may be regarded as being, if not strictly constant, at least nearly so over a wide range of feeding." It should be noted, however, that his statements relate in the main to Herbivora.

Benedict and Ritzman (*3*) state:

> It is reasonable to assume that the time-honored belief that domestic animals should be fed continually and fed to excess may be fairly challenged on two grounds: First, that the complete withdrawal of food for a few days is not injurious or distressing; second, that reasonably prolonged underfeeding is not distressing or permanently injurious.

At the Missouri station (*15*, *16*, *17*) beef animals were fed for extended periods at different levels of intake. One group was given all it would eat, another was fed at a level designed to obtain maximum growth without storage of surplus fat, and the third was distinctly retarded in growth by further limitation of feed. The decrease in feed level increased the quantity of feed required per unit of gain and produced carcasses containing decreased quantities of fat in the edible meat.

In a study of energy metabolism in relation to plane of nutrition in cattle, Forbes and associates (*5*) concluded that comparable determination of the specific dynamic effects of feedstuffs or nutrients can be determined only at the same plane of nutrition.

Mitchell and Hamilton (*14*) found that the percentage of available metabolizable energy of a 2-year-old steer at six levels of nutrition decreased with increase in the level of feeding. These workers also emphasized the fact that the net energy value of each ration must be expressed in relation to the dry-matter intake.

In studies on the growth of chickens, Jull and Titus (*11*) concluded that the relationship between growth and feed consumption is expressed by the law of diminishing increment. Subsequent work by Titus, Jull, and Hendricks [4] has led them to suggest underfeeding on an equal and uniform level in comparative feeding experiments. Such a procedure utilizes the paired-feeding method as applied by Mitchell and Beadles (*13*) but provides for a more uniform and graduated feeding schedule without greatly affecting the economy of gain.

The hog excels other farm animals in the economy of conversion of feed into edible body tissue. Henry and Morrison (*10*) point out that the hog not only has a low feed requirement per unit of gain but also yields a high percentage of dressed carcass. The edible portion of the carcass also has a high caloric value owing to the large quantity of fat stored during growth and fattening. Lusk (*12*) quotes Rubner as stating that growing hogs may store 40 percent of the caloric intake. Wilson, as reported by Lusk (*12*), found a 20-percent retention in young pigs on a milk diet. Armsby and Moulton (*2*) have calculated Swanson's data (*19*) in terms of gross efficiency and found the highest value to be about 39 percent. When corn was supplemented with protein and mineral elements, values of 30 percent or more were obtained in the usual case. Washburn and Jones (*20*) found a variation of from about 14 percent on skim milk to 44 percent on homogenized milk containing 8 percent of fat.

## PLAN OF EXPERIMENTS

The hog-feeding experiments were conducted between 1924 and 1932, inclusive. Eighty-nine pigs were individually fed weighed

[4] TITUS, H. W., JULL, M. A., and HENDRICKS, W. A. GROWTH OF CHICKENS AS A FUNCTION OF FEED CONSUMPTION. Unpublished manuscript.

amounts of the rations twice daily. Six additional pigs were self-fed in a group. Most of the pigs weighed between 55 and 80 pounds when they were placed on experiment. In the usual case, purebred Poland China, Chester White, Duroc-Jersey, and Tamworth pigs were used and were weighed weekly. The initial and final weights were usually based on the average of three successive daily weighings. At the beginning of the experiments, the pigs were taken directly from self-feeder lots and received the weighed amounts of feed, according to the schedule of feed levels, without any intervening transition period. In those pigs on the low level of feed, the decrease in feed consumption tended to cause a marked drop in weight very soon after the beginning of the experiment. The feed consumption was recorded on a weekly basis.

The animals were confined in paddocks and segregated according to feed levels. No green vegetation was available at any time. Feeding crates were provided so that at feeding time each pig could be confined in a separate compartment and fed individually. The pigs were released from the crates when all the feed was consumed. When pigs failed to eat, as occasionally occurred, the feed was weighed back.

In three experiments designated as A, B, and C, the rations contained peanuts as the basal feed. The initial weights of all the pigs in the three experiments ranged from 56 to 82 pounds. Experiment A, begun in December 1927 with fall pigs, consisted of two lots. One lot containing 4 pigs received individually a full feed, whereas the second lot, of 8 pigs, was fed approximately half the amount, per pig, fed to the first lot. The feed allowance was adjusted at weekly intervals to quantities such that the pigs on full feed readily consumed their portion in a reasonable time and those on the low level received approximately half this allowance. An intermediate feed level was included in experiments B and C. Experiment B contained 4 pigs in the full-feed lot, 4 in the intermediate, and 8 in the low-level lot. Experiment C contained 8, 4, and 8 pigs, respectively, in these lots. Experiment B was begun in July 1928 with spring pigs. The 4 pigs on the full-feed level were given a somewhat smaller allowance of feed than those in experiment A owing to disinclination to consume readily the original level as planned. The intermediate and low-level groups of experiment B were also reduced accordingly. Fall pigs were also used in experiment C which was begun in December 1929.

The several lots of pigs in experiments A and B received the peanut rations until the average gains of each lot reached 50 pounds but did not greatly exceed 60. The three lots in experiment C were fed the peanut ration until the gains were approximately 40 pounds. Thereafter, those hogs not slaughtered for analysis were fed a hardening ration usually on a full-feed basis.

The pigs in two experiments, designated as D and E, received rations containing corn as the basal feed. Experiment D was conducted in 1924 and experiment E in 1930–31. In experiment D, 3 pigs in one group were individually fed 60 percent as much as 3 animals in another group on full feed. A complex mineral mixture was self-fed separately from the grain ration.

In experiment E, begun in August 1930, three groups of pigs were fed at three levels. These levels were based on live weight but were

comparable to those for experiments B and C. One group of 6 pigs received 4 pounds of feed per 100 pounds of live weight, another group of 5 pigs 3 pounds, and the third group of 6 pigs 2 pounds. The quantity of feed was adjusted for each 20-pound increase in weight, based on group averages. Thus, on the 4-pound level of feeding the pigs weighing on the average between 60 and 79 pounds received 2.4 pounds of feed per day. When the average group weight was between 80 and 99 pounds, the feed allowance was raised to 3.2 pounds. Likewise, on the 3-pound level the feed allowances were 1.8 and 2.4 pounds, respectively, and on the 2-pound level the amounts of feed were 1.2 and 1.6 pounds, respectively. However, the method of feeding did not actually permit consumption of feed at the full levels of 4, 3, and 2 pounds per 100 pounds of live weight owing to the fact that the weight for calculation of the daily allowance was the lowest limit for the weight interval. All hogs in experiments D and E were fed to weights of approximately 200 pounds.

Finally a ration with wheat as the basal feed was used in experiment F. Three groups of six pigs, farrowed in the fall of 1931, were fed according to the same general plan followed in experiment E until their weights also approximated 200 pounds. In addition, six pigs were group fed with self-feeders until they weighed approximately the same as the other groups. The wheat ration just mentioned has been used with satisfactory results in other hog experiments at the United States Animal Husbandry Experiment Farm at Beltsville, Md. Adjustment of the daily feed allowances was made to permit the full intake of the 4-, 3-, and 2-percent levels by basing the calculation on the mid-point instead of the lowest point of the 20-pound weight interval.

The composition of the rations for the six experiments is given in table 1. The rations used in experiments A, B, and C were prepared with the view of providing for rapid growth on the full-feed levels. In this connection Hankins and Zeller (*9*) have shown that the efficiency of peanuts for growth of pigs is greatly increased by the addition of animal protein in the form of tankage. Halverson, Hostetler, and Sherwood (*6*) concluded that alfalfa meal and mineral mixture are effective as supplements to peanuts in producing satisfactory gains and that the further addition of animal protein supplements does not appear necessary. However, all these supplements and others were used in the present experiments.

TABLE 1.—*Percentage of different ingredients in rations used in experiments designated*

| Experiment | Peanuts, shelled | Corn, yellow | Wheat | Wheat middlings | Alfalfa-leaf meal | Linseed meal | Skim-milk powder | Tank-age | Mineral mixture |
|---|---|---|---|---|---|---|---|---|---|
| A | 70 | 14 | 0 | 0 | 5 | 3 | 0 | 7 | 1 |
| B | 80 | 0 | 0 | 0 | 7 | 4 | 0 | 8 | 1 |
| C [1] | 82.7 | 0 | 0 | 5 | 5 | 0 | 0 | 5 | 2.3 |
| D [2] | 0 | 50 | 0 | 40 | 0 | 0 | 0 | 10 | ([3]) |
| | 0 | 75 | 0 | 19 | 0 | 0 | 0 | 6 | ---------- |
| E | 0 | 84 | 0 | 0 | 5 | 0 | 0 | 9 | 2 |
| F | 0 | 0 | 84 | 0 | 5 | 0 | 5 | 5 | 1 |

[1] This ration was suggested by E. H. Hostetler and H. O. Halverson of the North Carolina Agricultural Experiment Station. It has been used in a number of experiments by several of the cooperating stations.

[2] The first set of figures shows the percentage of the different ingredients fed when the pigs weighed less than 100 pounds; the second set, when they weighed 100 pounds or more.

[3] A complex mineral mixture was self-fed separately from the grain ration.

The average chemical composition of the rations is shown in table 2. The percentages of the feeds used in experiment D were changed when the pigs reached a weight of 100 pounds in order to reduce the protein content. The rations used in experiments A, B, C, E, and F were not altered during the course of the experiments. The rations used in experiments A, B, and C were high in ether extract, owing to the peanut oil, and in protein, also contained in large part in the peanuts. The average protein content of the corn ration was 14.3 percent and the nutritive ratio approximately 1:6; the corresponding figures for the wheat ration were 17.4 percent and 1:6, respectively. The peanut rations contained approximately twice as much protein as the corn ration and were much higher in caloric value than either the corn or wheat rations because of the differences in the fat content.

TABLE 2.—*Chemical composition (percent) of the rations used in experiments designated*

| Experiment | Number of samples | Water | Protein | Ash | Ether extract | Fiber | Nitrogen-free extract |
|---|---|---|---|---|---|---|---|
| A | 1 | 5.5 | 27.1 | 3.9 | 34.2 | 3.3 | 26.0 |
| B | 2 | 5.5 | 28.6 | 5.0 | 34.2 | 4.3 | 22.4 |
| C | 1 | 4.4 | 29.6 | 4.6 | 35.0 | 3.6 | 22.8 |
| D [1] | 1 | 10.8 | 16.9 | [2] 4.5 | 4.3 | 4.3 | 59.2 |
| | 1 | 11.4 | 13.3 | [2] 3.1 | 4.1 | 3.3 | 64.8 |
| E | 3 | 9.8 | 14.3 | 4.2 | 4.3 | 2.9 | 64.5 |
| F | 3 | 11.2 | 17.4 | 4.0 | 2.3 | 2.9 | 62.2 |

[1] The first set of figures shows the chemical composition of the ration fed while the pigs weighed less than 100 pounds; the second set, after they had attained this weight.
[2] Not including self-fed minerals.

Analyses were made of the carcasses of seven animals from experiments A and B, in which peanuts were fed, of 15 animals from experiment E, in which corn was fed, and of 18 individually fed animals from experiment F, in which wheat was fed. In addition, analyses of back fat were made on six self-fed animals in experiment F. The first-named lot of seven hogs consisted of selected animals which were slaughtered at weights ranging from 109 to 126 pounds immediately after the peanut-feeding period. From the full-fed groups, two hogs from experiment A and one from experiment B were used, and from the low-level groups two each were taken from experiments A and B. As each hog in experiments E and F attained a weight of approximately 200 pounds, it was removed from the feed lot. Feed was withheld for a day and the animal slaughtered.

At the time of slaughter the blood, hair, and all viscera from all hogs were saved, except those in experiment F. The stomachs and intestines were cleaned, and a composite sample of all visceral organs was prepared for each hog. Lot samples of blood and dried hair were also prepared. In the case of all the experimental hogs, after the warm dressed carcasses were weighed they were refrigerated for 3 days and then graded for firmness. Subsequently, fat samples were taken from all hogs after which the carcasses were separated into commercial cuts. The cuts were separated into lean, fat, bone, and skin fractions. The procedure throughout was essentially that usually followed in the cooperative investigations on quality of meats. The cutting methods have been described by Warner et al.[5] Analyti-

[5] WARNER, K. F., ELLIS, N. R., and HOWE, P. E. CUTTING YIELDS OF HOGS AN INDEX OF FATNESS. Jour. Agr. Research 48. 241-255, illus. 1934.

cal samples were prepared for certain cuts, including the lean and the fat of the ham, the loin, the back fat, and the remaining edible meat which was made into a composite sample. The total skin and the bone were also sampled for all the hogs except those in experiment F.

A number of hams from hogs on the 4- and 2-percent feed levels from experiments E and F were cooked, and palatability tests made in order to determine whether the low level of feeding had any pronounced effect on the quality of the meat.

## EXPERIMENTAL RESULTS

### EFFECTS OF FEEDING LEVEL ON ECONOMY OF GAINS

#### PEANUTS AS THE BASAL FEED

The feeding results obtained in experiments A, B, and C are shown in tables 3, 4, and 5. The daily feed consumption on the full-feed level of the peanut rations was lower for all the animals than is usually the case with pigs weighing not greatly more or less than 100 pounds and fed on cereal rations. As an example, compared with a daily intake of 4 pounds, the estimated consumption of feed per 100 pounds of live weight of the hogs in the full-fed lot in experiment B was 2.94 pounds. However, this quantity of feed had approximately the same caloric value as 4.4 pounds of the ration of corn and supplements used in experiment E. The small decrease in daily feed consumption in experiment B from that of the corresponding lots in experiment A was reflected to a slight extent in a decrease in the average daily gains of the animals. However, the feed required per 100 pounds of gain for comparable feed levels shows good agreement. The four pigs on the intermediate level in experiment B were exceptional in that they gained the most rapidly and required the least feed per 100 pounds' weight of any lot.

TABLE 3.—*Comparison of gains and feed consumption of pigs in experiment A on high and low levels of a peanut ration*

| Feeding level | Hog no. | Breed [1] | Sex | Initial weight | Experimental period | Total gain | Average daily gain | Total feed | Feed consumption per 100 pounds' gain |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Lb.* | *Days* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| High (full feed) | 1 | CW | Barrow | 65 | 42 | 48 | 1.14 | 136.2 | 283.9 |
| | 2 | CW | do | 63 | 47 | 51 | 1.09 | 158.8 | 311.3 |
| | 3 | PC | do | 56 | 42 | 53 | 1.26 | 132.7 | 250.5 |
| | 4 | PC | do | 72 | 47 | 51 | 1.09 | 158.8 | 311.3 |
| Average | | | | 64 | 44.5 | 50.8 | 1.15 | 146.6 | 289.2 |
| Low (55 percent of full feed) | 5 | CW | Barrow | 64 | 61 | 51 | .84 | 112.5 | 220.6 |
| | 6 | CW | Gilt | 70 | 61 | 58 | .95 | 109.0 | 187.9 |
| | 7 | CW | Barrow | 57 | 54 | 52 | .96 | 89.8 | 172.6 |
| | 8 | CW | do | 57 | 61 | 58 | .95 | 110.7 | 190.9 |
| | 9 | PC | Gilt | 65 | 68 | 45 | .66 | 131.7 | 292.8 |
| | 10 | PC | do | 57 | 61 | 58 | .95 | 110.7 | 190.9 |
| | 11 | PC | do | 71 | 61 | 57 | .93 | 109.0 | 191.2 |
| | 12 | PC | Barrow | 63 | 61 | 55 | .90 | 109.0 | 198.2 |
| Average | | | | 63 | 61 | 54.3 | .89 | 110.3 | 205.6 |

[1] CW=Chester White; PC=Poland China.

TABLE 4.—*Comparison of gains and feed consumption of pigs in experiment B on 3 levels of a peanut ration*

| Feeding level | Hog no. | Breed [1] | Sex | Initial weight | Experimental period | Total gain | Average daily gain | Total feed | Feed per 100 pounds' gain |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Lb.* | *Days* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| High (full feed) | 13 | CW | Gilt | 73 | 63 | 69 | 1.10 | 181.5 | 263.0 |
| | 14 | DJ | do | 58 | 63 | 58 | .92 | 181.5 | 312.9 |
| | 15 | PC | do | 67 | 63 | 69 | 1.10 | 181.5 | 263.0 |
| | 16 | T | Barrow | 72 | 70 | 50 | .71 | 200.2 | 400.5 |
| Average | | | | 67.5 | 64.8 | 61.5 | .96 | 186.2 | 309.9 |
| Medium (70 percent of full feed) | 17 | DJ | Barrow | 79 | 48 | 59 | 1.23 | 107.8 | 182.6 |
| | 18 | CW | Gilt | 82 | 48 | 53 | 1.10 | 107.8 | 203.3 |
| | 19 | CW | Barrow | 80 | 48 | 60 | 1.25 | 107.8 | 179.6 |
| | 20 | CW | Gilt | 80 | 48 | 48 | 1.00 | 107.8 | 224.5 |
| Average | | | | 80.3 | 48 | 55 | 1.15 | 107.8 | 197.5 |
| Low (50 percent of full feed) | 21 | CW | Barrow | 68 | 63 | 51 | .81 | 85.2 | 167.2 |
| | 22 | CW | Gilt | 72 | 77 | 56 | .73 | 108.0 | 192.9 |
| | 23 | CW | Barrow | 65 | 77 | 57 | .74 | 106.2 | 186.4 |
| | 24 | CW | do | 67 | 70 | 51 | .73 | 108.0 | 211.8 |
| | 25 | CW | Gilt | 72 | 77 | 58 | .75 | 108.0 | 186.2 |
| | 26 | DJ | Barrow | 61 | 91 | 47 | .52 | 133.8 | 284.6 |
| | 27 | PC | Gilt | 71 | 70 | 51 | .73 | 95.7 | 187.8 |
| | 28 | T | Barrow | 64 | 84 | 57 | .68 | 116.8 | 204.8 |
| Average | | | | 67.5 | 76 | 53.5 | .71 | 107.7 | 202.7 |

[1] CW=Chester White; DJ=Duroc-Jersey; PC=Poland China; T=Tamworth.

TABLE 5.—*Comparison of gains and feed consumption of pigs in experiment C on 3 levels of a peanut ration*

| Feeding level | Hog no. | Breed [1] | Sex | Entire experimental period | | | | | | First 3 weeks of entire experimental period omitted | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Initial weight | Experimental period | Total gain | Average daily gain | Total feed | Feed per 100 pounds' gain | Experimental period | Total gain | Average daily gain | Total feed | Average feed per 100 pounds' gain |
| | | | | *Pounds* | *Days* | *Pounds* | *Pounds* | *Pounds* | *Pounds* | *Days* | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| High (full feed) | 29 | CW | Barrow | 67 | 56 | 40 | 0.72 | 170.5 | 426.3 | 35 | 32 | 0.91 | 113.5 | 354.7 |
| | 30 | CW | Gilt | 64 | 56 | 39 | .70 | 167.0 | 428.1 | 35 | 32 | .91 | 110.0 | 343.7 |
| | 31 | CW | do | 66 | 56 | 46 | .82 | 170.5 | 370.7 | 35 | 37 | 1.06 | 113.5 | 306.8 |
| | 32 | CW | do | 60 | 70 | 40 | .57 | 218.0 | 545.0 | 49 | 38 | .78 | 161.0 | 423.7 |
| | 33 | CW | Barrow | 72 | 70 | 41 | .59 | 219.5 | 535.4 | 49 | 43 | .88 | 162.5 | 377.9 |
| | 34 | DJ | do | 67 | 56 | 43 | .71 | 169.0 | 393.0 | 35 | 28 | .80 | 112.0 | 400.0 |
| | 35 | DJ | Gilt | 64 | 63 | 39 | .62 | 197.0 | 505.1 | 42 | 30 | .72 | 140.0 | 466.7 |
| | 36 | PC | do | 60 | 70 | 37 | .53 | 214.5 | 579.7 | 49 | 37 | .76 | 157.5 | 425.7 |
| Average | | | | 65 | 62 | 40.6 | .66 | 190.8 | 472.9 | 41 | 34.4 | .85 | 133.7 | 387.4 |
| Medium (70 percent of full feed) | 37 | CW | Gilt | 79 | 49 | 41 | .84 | 98.0 | 239.0 | 28 | 28 | 1.00 | 45.5 | 162.5 |
| | 38 | CW | Barrow | 67 | 63 | 36 | .57 | 143.7 | 399.3 | 42 | 37 | .88 | 91.2 | 246.6 |
| | 39 | CW | do | 63 | 63 | 43 | .68 | 143.7 | 334.4 | 42 | 42 | 1.00 | 91.2 | 217.3 |
| | 40 | DJ | do | 66 | 56 | 41 | .73 | 113.8 | 277.4 | 35 | 33 | .94 | 61.3 | 185.6 |
| Average | | | | 68.8 | 58 | 40.2 | .70 | 124.8 | 312.5 | 37 | 35 | .95 | 72.3 | 203.0 |
| Low (50 percent of full feed) | 41 | CW | Gilt | 60 | 76 | 47 | .62 | 111.0 | 236.2 | 55 | 45 | .82 | 84.0 | 186.7 |
| | 42 | CW | Barrow | 67 | 76 | 50 | .66 | 110.3 | 220.5 | 55 | 44 | .80 | 83.2 | 189.2 |
| | 43 | CW | Gilt | 67 | 76 | 34 | .45 | 111.0 | 326.5 | 55 | 28 | .51 | 84.0 | 300.0 |
| | 44 | CW | do | 69 | 76 | 41 | .54 | 111.0 | 270.7 | 55 | 42 | .76 | 84.0 | 200.0 |
| | 45 | CW | Barrow | 64 | 76 | 41 | .54 | 111.0 | 270.7 | 55 | 36 | .66 | 84.0 | 233.3 |
| | 46 | DJ | Gilt | 61 | 76 | 44 | .58 | 111.0 | 252.3 | 55 | 41 | .75 | 84.0 | 204.9 |
| | 47 | DJ | Barrow | 68 | 76 | 37 | .49 | 111.0 | 300.0 | 55 | 40 | .73 | 84.0 | 210.0 |
| | 48 | PC | do | 62 | 76 | 31 | .41 | 109.5 | 353.2 | 55 | 26 | .47 | 82.5 | 317.3 |
| Average | | | | 64.8 | 76 | 40.6 | .54 | 110.8 | 278.8 | 55 | 37.8 | .69 | 83.6 | 230.2 |

[1] CW=Chester White; DJ=Duroc-Jersey; PC=Poland China.

The performance of all the hogs for the entire period in experiment C was poor. This was especially marked in the group on full feed, not only in rate of gain but in feed required per 100 pounds of gain. It is noteworthy that the feed required per 100 pounds of gain was less on the limited feed levels, as occurred in experiments A and B.

During the first 3 weeks of experiment C, the full-fed hogs gained approximately 5 pounds and the medium and the low-level groups 3 pounds each. After this period of poor gains the growth rate improved. Insufficient evidence was available to indicate whether the failure of the hogs to gain during the early part of the experimental period was due to sickness incurred before the beginning of the experiment or to the abrupt change in ration and method of feeding. The results of the experiment, when the data for the first 3 weeks of all lots are excluded, as shown in table 5, indicate that the daily gains and the feed utilization were not greatly different for the remainder of the experiment from those of the earlier experiments.

The results obtained from this recalculation show the highest rate of gain and the best utilization of feed to be on the medium level of feed intake. The latter observation is not in harmony with the figures for the entire experimental period since the low-level group required only 278.8 pounds of feed per 100 pounds of gain compared with 312.5 pounds for the medium level. The significance of the difference between the means of (1) the average daily gains and (2) the feed consumed per unit gain, has been tested according to the method for $t$ test given by Fisher (*4, p. 109*). Only the high and the low levels have been compared, but the $t$ value has been calculated for the two sets of results for experiment C taken from table 5. The value of $t$ for the two comparisons of average daily gains correspond, in terms of $P$, to 0.02, which means that the chances are 49 to 1 that the differences are significant. The comparisons of feed consumed per unit gain yield values for $t$ which indicate that the chances are greater than 99 to 1 that the differences are significant. The order of significance was nearly identical for the two sets of data based either on inclusion or exclusion of the first 3 weeks of the feeding period. Since the differences due to level of feed intake in experiments A and B are in general accord with those in experiment C (table 5) both with and without the questionable 3-week period included, there appears little reason to doubt the significance of the differences produced by feed level.

The growth curves of the hogs, based on lot averages, are shown in figure 1 for each of the three experiments. It will be noted that in experiments B and C the curves for the medium-level lots closely follow those of the high-level lots. In both experiments the medium-level lots have increased rates of gain midway in the period and the gain curves remain above those of the high-level lots until the end of the periods.

Although growth was retarded on the low level of intake in all the experiments, the gains were made more efficiently in terms of feed consumption than on the high level and were not greatly different from those on the medium level. The feed requirements for unit gain on the high, or full-feed, level were generally lower than is found on peanut rations under the usual feeding conditions. As already indicated, this may be accounted for by the evidently high caloric value of peanuts, owing to oil content, and also to the high protein content.

Values such as were obtained on the high-level groups have been noted in other peanut-feeding experiments (*7*, *8*, *9*) in which the hogs were

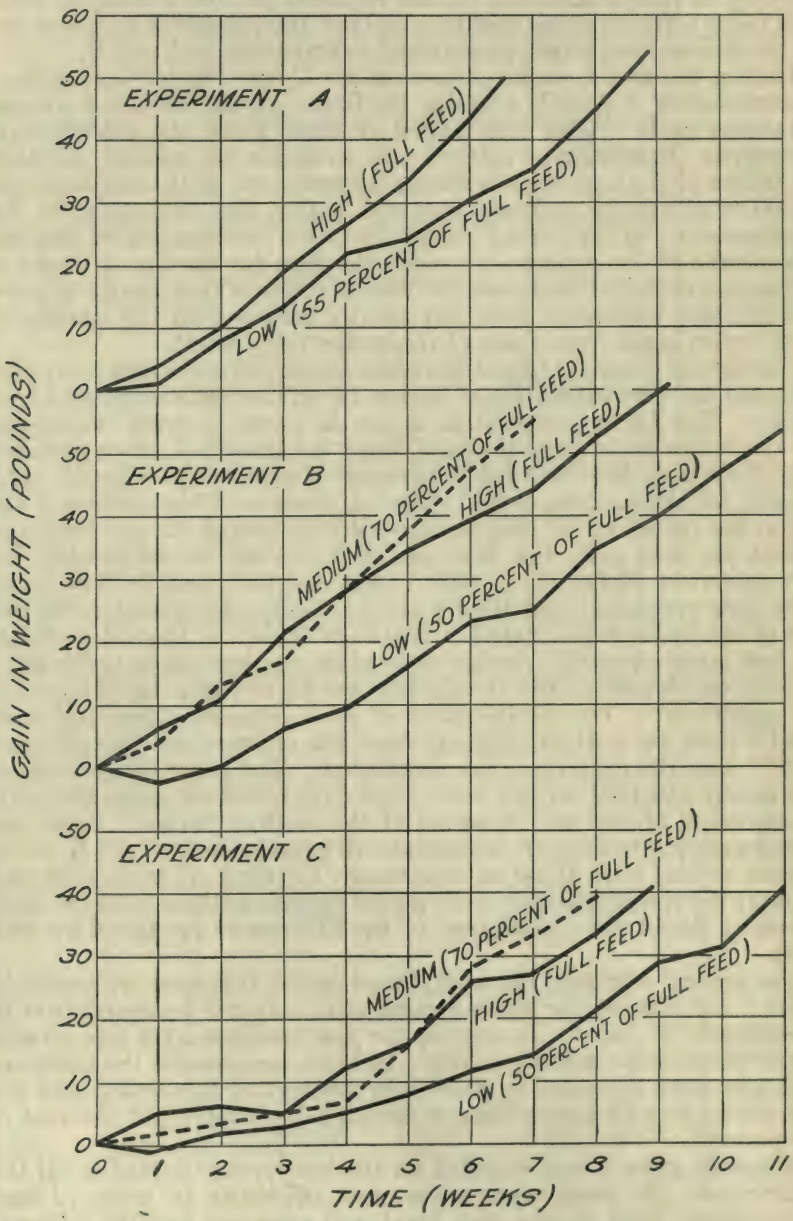
EXPERIMENT A
HIGH (FULL FEED)
LOW (55 PERCENT OF FULL FEED)
EXPERIMENT B
MEDIUM (70 PERCENT OF FULL FEED)
HIGH (FULL FEED)
LOW (50 PERCENT OF FULL FEED)
EXPERIMENT C
MEDIUM (70 PERCENT OF FULL FEED)
HIGH (FULL FEED)
LOW (50 PERCENT OF FULL FEED)
GAIN IN WEIGHT (POUNDS)
TIME (WEEKS)
0 10 20 30 40 50 60
0 1 2 3 4 5 6 7 8 9 10 11

FIGURE 1.—Average gains, by weekly periods, of the lots of pigs fed peanut rations at high, medium, and low levels.

self-fed in groups. Results on 316 hogs (*7*) fed unshelled peanuts and a mineral mixture showed that the animals consumed, per 100 pounds of gain, 351.9 pounds of peanuts, the equivalent of approxi-

mately 275 pounds of shelled nuts. However, the shelled peanuts used in experiments A, B, and C, although representative of the product usually marketed for hog feeding, were not equal in feeding value, as judged by the chemical composition, to the usual quality and yield of nuts obtained by hand shelling whole nuts, which was done in order to obtain the above estimate of equivalent values of whole and shelled nuts.

The hogs of experiments A, B, and C which were not slaughtered at the conclusion of the peanut-feeding period were individually fed a hardening ration of corn and supplements. Although the details of the hardening results are not given in this bulletin, it is of interest that the restriction of the peanut ration had little, if any, effect on the gains and feed utilization on the hardening ration. Twenty hogs from the lots on the low levels of the peanut rations gained an average of 1.61 pounds per day and consumed 424.4 pounds of feed per 100 pounds of gain, whereas 13 hogs from the high-level lots gained at the rate of 1.53 pounds and consumed 437.6 pounds of feed.

### CORN AS THE BASAL FEED

The results on gains and feed consumption for experiment D are given in table 6. The daily feed of the full-fed lot on the corn ration, as calculated from the average weight, total feed consumption, and days on experiment, averaged 3.63 pounds and the 60-percent lot averaged 2.38 pounds per 100 pounds' live weight. On the basis of 4 percent of the live weight as approximately a full feed for hogs ranging from 50 to 200 pounds in weight, the consumption of these hogs was below the average. As indicated by the growth curves of the hogs, shown in figure 2, little difference in rate of growth existed between the two groups of hogs. The best gains were made after the hogs passed the 100-pound weight. The feed required per 100 pounds of gain was higher for hog 51 than is usually associated in practical feeding with thrifty, economical gains. The remaining two hogs on full feed showed satisfactory feed utilization according to the usual standards. The lowering of the daily feed allowance of three hogs to 60 percent of the full ration resulted in correspondingly lower feed requirement per unit gain.

TABLE 6.—*Comparison of gains and feed consumption of pigs in experiment D on 2 levels of a corn ration*

| Feeding level | Hog no. | Breed [1] | Sex | Initial weight | Experimental period | Total gain | Average daily gain | Total feed | Average feed per 100 pounds' gain |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Lb.* | *Days* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| High (full feed) | 49 | T×gr. PC | Barrow | 64 | 130 | 135 | 1.04 | 615.0 | 455.6 |
| | 50 | PC | Gilt | 64 | 130 | 146 | 1.12 | 615.0 | 421.2 |
| | 51 | T | do | 55 | 160 | 152 | .95 | 804.0 | 528.9 |
| Average | | | | 61 | 140 | 144 | 1.04 | 678.0 | 468.6 |
| Low (60 percent of full feed) | 52 | CW | Gilt | 57 | 130 | 139 | 1.07 | 382.0 | 274.8 |
| | 53 | PC | Barrow | 58 | 160 | 150 | .94 | 498.3 | 332.2 |
| | 54 | T | Gilt | 54 | 160 | 144 | .90 | 498.2 | 346.0 |
| Average | | | | 56 | 150 | 144 | .97 | 459.5 | 317.7 |

[1] CW=Chester White; PC=Poland China; T=Tamworth; T×gr.PC=Tamworth cross on grade Poland China.

The effect of feeding a corn ration at different feeding levels was further studied in experiment E. The results are given in table 7. The rate of growth as related to length of feeding period is shown in figure 2. The curves indicate that the rate of growth increased in

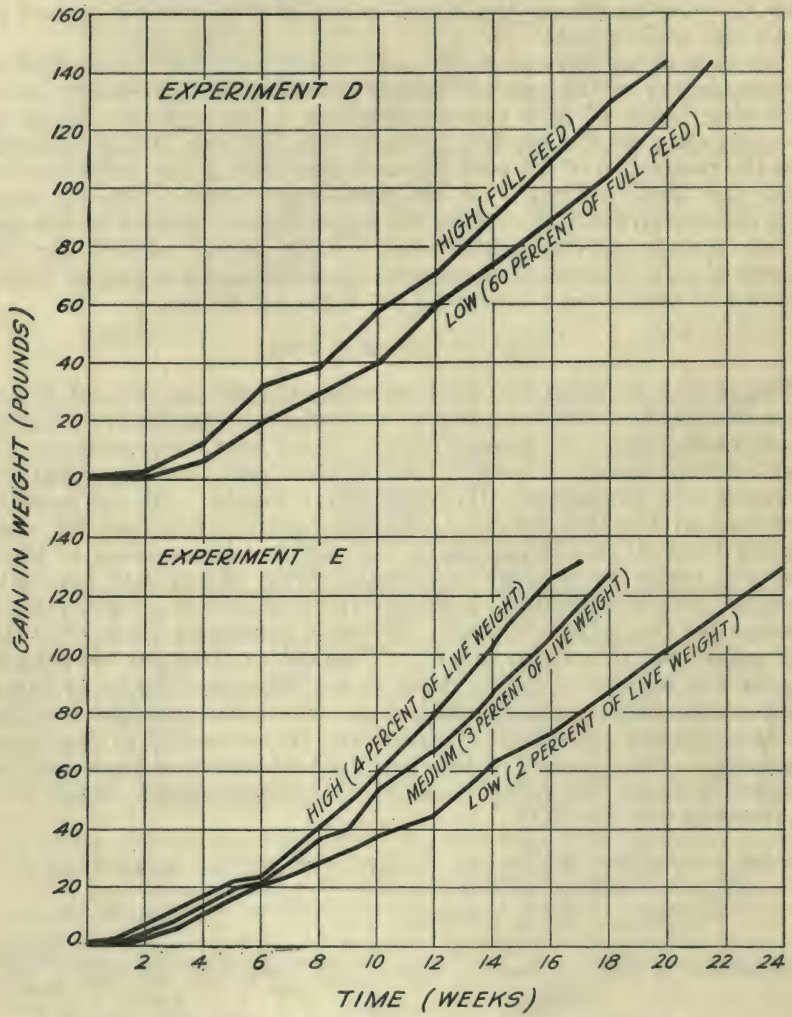


FIGURE 2.—Average gains, by weekly periods, of the lots of pigs fed corn rations at high and low levels in experiment D and high, medium, and low levels in experiment E.

all lots proportionally to the feeding level with increasing live weight. Thus, the curve for the lot on the low allowance of feed appears to deviate the least from a straight line and the curve for the lot on the full allowance the most.

TABLE 7.—*Comparison of gains and feed consumption of pigs in experiment E on 3 levels of a corn ration*

| Feeding level | Hog no. | Breed [1] | Sex | Initial weight | Experimental period | Total gain | Average daily gain | Total feed | Average feed per 100 pounds' gain |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Lb.* | *Days* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| High (4 percent of live weight). | 55 | CW | Gilt | 73 | 115 | 124 | 1.08 | 529.6 | 427.1 |
| | 56 | CW | Barrow | 72 | 115 | 133 | 1.16 | 529.6 | 398.2 |
| | 57 | CW | Gilt | 67 | 115 | 132 | 1.15 | 522.4 | 395.7 |
| | 58 | DJ | do | 62 | 127 | 132 | 1.04 | 620.8 | 470.3 |
| | 59 | PC | Barrow | 74 | 115 | 155 | 1.35 | 528.2 | 340.8 |
| | 60 | PC | do | 62 | 127 | 136 | 1.07 | 620.8 | 456.5 |
| Average | | | | 68.3 | 119 | 135.3 | 1.14 | 558.6 | 414.8 |
| Medium (3 percent of live weight). | 61 | CW | Gilt | 67 | 135 | 123 | .91 | 503.0 | 408.9 |
| | 62 | CW | Barrow | 76 | 115 | 124 | 1.08 | 388.2 | 313.1 |
| | 63 | DJ | Gilt | 72 | 127 | 125 | .98 | 449.8 | 359.8 |
| | 64 | PC | do | 62 | 135 | 141 | 1.05 | 502.0 | 356.0 |
| | 65 | PC | Barrow | 64 | 127 | 146 | 1.15 | 448.8 | 307.4 |
| Average | | | | 68.2 | 127.8 | 131.8 | 1.03 | 458.4 | 349.0 |
| Low (2 percent of live weight). | 66 | CW | Gilt | 72 | 167 | 124 | .74 | 395.5 | 318.9 |
| | 67 | CW | do | 72 | 167 | 132 | .79 | 397.8 | 301.4 |
| | 68 | CW | do | 62 | 167 | 135 | .81 | 397.8 | 294.7 |
| | 69 | DJ | do | 77 | 167 | 120 | .72 | 397.8 | 331.5 |
| | 70 | PC | Barrow | 73 | 147 | 125 | .85 | 326.9 | 261.5 |
| | 71 | CW×Y | do | 52 | 182 | 131 | .72 | 454.8 | 347.2 |
| Average | | | | 68 | 166 | 127.8 | .77 | 395.1 | 309.2 |

[1] CW=Chester White; DJ=Duroc-Jersey; PC=Poland China; Y=Yorkshire.

Arrangement of the feeding and growth data in the form given in table 8 shows the average gains by successive 100-pound increments of feed intake. Adequate data on this phase of the study were obtained only in experiments E and F. Smoothed growth curves were first constructed from the running averages of three successive weekly weights of the individual pigs in order to remove occasional irregularities in weights. The gain in weight for each 100 pounds of feed intake was then obtained.

TABLE 8.—*Comparison of gains in weight (pounds) per successive 100 pounds of feed increment consumed at 3 levels of feeding in experiment E*

| Feed increment | High level | Medium level | Low level |
|---|---|---|---|
| First 100 pounds | 22.0 | 25.6 | 31.8 |
| Second 100 pounds | 24.0 | 31.8 | 36.0 |
| Third 100 pounds | 28.7 | 30.4 | 33.8 |
| Fourth 100 pounds | 26.3 | 29.2 | 28.2 |
| Fifth 100 pounds | 23.8 | | |

It will be noted that the hogs on the high level made the greatest gain on the third 100-pound increment of feed, which occurred between weights of approximately 110 and 140 pounds. Greater gains on all corresponding feed increments occurred on the medium and low levels than on the high level. Apparently, the highest gains occurred in all lots during the second or third 100 pounds of feed intake and tended to decrease thereafter. The most pronounced decrease in efficiency of conversion of feed into body weight occurred in the high-level lot. The small decreases for the lots on the medium and low levels are undoubtedly indicative of increasing maintenance requirements resulting from increasing growth.

Table 7 shows that the total gains in weight of the 17 hogs ranged from 120 to 155 pounds with the lot averages within the range of 128 to 135 pounds. The time required to reach the desired gain increased

from 119 to 166 days with the decrease in the feed level. Although the time required to reach a final weight of approximately 200 pounds was increased by limitation of the feed to 2 percent of the live weight of the animal, the total feed consumption was reduced fully 25 percent. The lot on the medium level of feeding gave results intermediate to the high- and low-level lots. In the experiments with the peanut rations the hogs on the medium levels tended to gain at rates slightly better than those on the full levels and at the same time utilized the peanut ration fully as well, if not better, than those on the low levels of feeding.

The differences in feed economy between lots are of such size as to indicate a significantly better utilization of feed with decreasing intake with the levels used. Although the numbers of hogs are small within any one group, there is a consistent trend from group to group. A study of the significance of the mean differences (*4, p. 109*) in the feed required per unit gain between the lots shows $P$ values to be

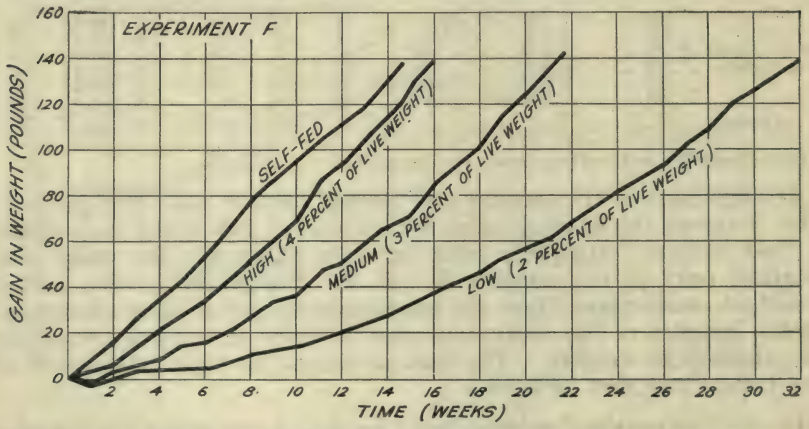


FIGURE 3.—Average gains, by weekly periods, of lots of pigs in experiment F fed a wheat ration at high, medium, and low levels, and of one lot self-fed the same ration.

less than 0.04 for lots on the high and medium levels and less than 0.01 for lots on the high and low levels. With odds greater than 24 to 1 and 99 to 1, as indicated by the values for $P$, the medium- and low-level lots appear to have made a significantly better utilization of the feed than the high-level lot, even though the hogs required a longer time to reach the same final weight. The data show a lack of significance in the feed requirements between the lots on the medium and low levels of feeding.

### WHEAT AS A BASAL FEED

The feeding of a ration low in fat and normal in protein content, such as is found in the corn ration previously described, as distinguished from the high-fat and high-protein peanut ration, was continued in experiment F. Wheat replaced corn as the basal feed. As already noted, the plan of work for experiment F followed that of experiment E in most details. One additional lot on a self-fed basis was included for feed and growth comparisons with the feeding levels of 4, 3, and 2 percent of live weight. The results of this experiment are shown in table 9.

TABLE 9.—*Comparison of gains and feed consumption of the 4 lots of pigs in experiment F on a wheat ration*

| Feeding level | Hog no. | Breed [1] | Sex | Initial weight | Experimental period | Total gain | Average daily gain | Total feed consumption | Average feed per 100 pounds' gain |
|---|---|---|---|---|---|---|---|---|---|
| | | | | *Lb.* | *Days* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| High (4 percent of live weight) | 72 | CW | Barrow | 57 | 111 | 141 | 1.27 | 524.0 | 371.6 |
| | 73 | CW | Gilt | 59 | 111 | 151 | 1.36 | 524.0 | 347.0 |
| | 74 | DJ | do | 69 | 111 | 144 | 1.30 | 524.0 | 363.9 |
| | 75 | DJ | Barrow | 67 | 111 | 135 | 1.22 | 524.0 | 388.2 |
| | 76 | PC | do | 64 | 125 | 142 | 1.14 | 636.0 | 447.9 |
| | 77 | PC | do | 62 | 111 | 143 | 1.29 | 524.0 | 366.4 |
| Average | | | | 63 | 113 | 142.7 | 1.26 | 542.7 | 380.4 |
| Medium (3 percent of live weight) | 78 | CW | Gilt | 68 | 141 | 132 | .94 | 450.5 | 341.3 |
| | 79 | CW | do | 52 | 153 | 157 | 1.03 | 517.3 | 329.5 |
| | 80 | DJ | Barrow | 71 | 153 | 137 | .90 | 515.7 | 376.5 |
| | 81 | DJ | Gilt | 53 | 153 | 154 | 1.01 | 515.7 | 334.9 |
| | 82 | PC | Barrow | 71 | 153 | 130 | .85 | 517.3 | 397.9 |
| | 83 | PC | do | 53 | 153 | 150 | .98 | 517.3 | 344.8 |
| Average | | | | 61.3 | 151 | 143.3 | .95 | 505.6 | 354.2 |
| Low (2 percent of live weight) | 84 | CW | Gilt | 55 | 231 | 150 | .65 | 510.0 | 340.0 |
| | 85 | CW | do | 57 | 231 | 142 | .61 | 510.0 | 359.2 |
| | 86 | DJ | Barrow | 70 | 210 | 133 | .63 | 435.9 | 327.7 |
| | 87 | DJ | do | 65 | 231 | 136 | .59 | 510.0 | 375.0 |
| | 88 | PC | do | 78 | 231 | 126 | .55 | 510.0 | 404.8 |
| | 89 | PC | Gilt | 55 | 210 | 146 | .70 | 435.9 | 298.5 |
| Average | | | | 63.3 | 224 | 138.8 | .62 | 485.3 | 349.6 |
| Self-fed | 90 | CW | Barrow | 78 | 69 | 125 | 1.81 | | |
| | 91 | CW | Gilt | 60 | 111 | 145 | 1.31 | | |
| | 92 | DJ | Barrow | 56 | 111 | 154 | 1.39 | | |
| | 93 | DJ | do | 79 | 97 | 130 | 1.34 | | |
| | 94 | PC | Gilt | 61 | 125 | 146 | 1.17 | | |
| | 95 | PC | do | 64 | 86 | 148 | 1.72 | | |
| Average | | | | 66.3 | 100 | 141.3 | 1.45 | 707.2 | 500.4 |

[1] CW = Chester White; DJ = Duroc-Jersey; PC = Poland-China.

The gains in weight as related to length of feeding period of the four lots of hogs are shown in figure 3. The most pronounced differences in rate of gain occurred during the early part of the experiment. Indeed, the low-level group failed to gain until the third week of the experiment, and it was not until after the seventh week that a reasonably rapid rate of gain was maintained. Several factors are possibly involved, namely, the "fill" at the beginning of the experiment, the disturbance to health and to normal body functions owing to decrease in feed, or other factors. A similar situation occurred in experiment C. In this case, however, all groups were affected, thus indicating with greater certainty that factors other than feed level were predominant. When once adjusted to these factors causing the early retardation, the lot on the low level of feeding in experiment F gained as well as the corresponding lot in experiment E. Indeed, the growth curve of the two experiments are much alike except for the early retardation as noted.

A tabulation of the data according to gain per 100 pounds of feed increments, as was presented for experiment E, yielded the results given in table 10. The high-level group showed the most efficient utilization of feed in the first 100 pounds consumed but was never greatly in excess and usually less than the two lower-level groups on all successive 100-pound increments.

TABLE 10.—*Comparison of gains in weight (pounds) for successive 100 pounds of feed consumed at 3 levels of feeding in experiment F (wheat ration)*

| Feed increment | High level | Medium level | Low level |
|---|---|---|---|
| First 100 pounds | 29.0 | 20.8 | 17.5 |
| Second 100 pounds | 29.3 | 32.5 | 28.5 |
| Third 100 pounds | 29.5 | 28.7 | 37.5 |
| Fourth 100 pounds | 22.8 | 30.8 | 30.5 |
| Fifth 100 pounds | 21.5 | 29.4 | 28.5 |

The slow gains during the early weeks on the low level of feeding were responsible for the low gain, 17.5 pounds, shown in table 10. On the other hand, the high gain attained on the second 100 pounds of feed increment on the low level was maintained until the end; on the medium level there was only a slight decrease; but on the high level a decided decrease occurred on the fourth and fifth 100-pound increments. The low-level group made a maximum gain per unit of feed intake between weights of approximately 115 and 150 pounds.

The growth and feed-consumption results for the entire experiment, as shown in table 9, indicate that the self-fed group made the highest average daily gain, but also consumed the largest quantity of feed per 100 pounds of gain. Although the requirement of 500.4 pounds of feed per 100 pounds of gain appears high, data from other experiments conducted at the same time showed equally high feed consumption when the animals were self-fed.[6]

The lots on the 4-, 3-, and 2-percent feed levels ranked in decreasing order not only for rate of growth but for feed requirement per 100 pounds of gain. The differences among the three groups in feed requirements were not so great as in experiment E. Statistical tests applied to the data in experiment F showed no significant differences between mean values of the groups. However, a study of the hogs from the same litter as distributed among the four lots indicated that litter mates on the lower feed level gained consistently more economically and thus supports the order of efficiency indicated by the group averages.

### EFFECTS OF FEEDING LEVEL ON PHYSICAL AND CHEMICAL COMPOSITION OF THE HOGS

#### PEANUTS AS THE BASAL FEED

The composition of the entire bodies of three hogs from the high feeding levels and four hogs from the low levels on the peanut ration, the hogs being killed at approximately the same weights, is shown in table 11. The limitation of the daily ration to 50 or 55 percent of the full feed did not materially lower the fatness of the carcasses. The average percentage of fat differed by only 0.6 between the two groups. Furthermore, the average fat composition of these seven hogs was higher than that of hogs of similar weights taken from other experiments and self-fed on rations low in fat. Twelve such hogs showed an average fat content of 26.5 percent. However, results obtained on the hogs changed to hardening feed indicated a wider ratio of soft fat to hard fat in the carcasses of the hogs fed on the low level than in those on the full-feed level, thus showing a favorable effect on firmness through restriction of softening feed.

[6] Unpublished data.

TABLE 11.—*Comparison of the composition of the bodies of peanut-fed hogs fed at high and low levels*

| Feeding level | Experiment | Hog no. | Live weight | Weights of parts analyzed | Composition of entire body | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Water | Protein | Fat | Ash |
| | | | *Pounds* | *Pounds* | *Percent* | *Percent* | *Percent* | *Percent* |
| High (full feed) | A | 1 | 113 | 97.9 | 55.1 | 13.9 | 27.7 | 3.0 |
| | A | 3 | 109 | 96.2 | 56.3 | 13.5 | 26.9 | 3.0 |
| | B | 16 | 126 | 111.3 | 51.8 | 13.2 | 31.5 | 2.9 |
| Average | | | 115 | 101.8 | 54.4 | 13.5 | 28.7 | 3.0 |
| Low (50–55 percent of full feed) | A | 5 | 112 | 102.9 | 54.3 | 14.2 | 28.3 | 2.8 |
| | A | 10 | 111 | 103.1 | 55.9 | 14.3 | 26.7 | 3.1 |
| | B | 24 | 122 | 107.2 | 55.3 | 14.1 | 27.2 | 2.9 |
| | B | 28 | 121 | 104.4 | 53.1 | 13.9 | 30.2 | 3.3 |
| Average | | | 116 | 104.4 | 54.6 | 14.1 | 28.1 | 3.0 |

CORN AS THE BASAL FEED

After the slaughter of the hogs in experiment E at weights of approximately 200 pounds, both physical and chemical analyses were made on the body parts of five hogs from each lot. The average percentage cutting yields for the principal cuts of the cold carcasses are given in table 12. A small but generally consistent difference was found between lots for the lean cuts (ham, shoulder, and loin) on the one hand, and for the fat cuts (belly, back fat, and cutting fat) on the other. Cutting fat, as here used, consists of the skinless back fat and fat trimmings and the leaf fat. The lean cuts increased with decrease in feed level and the fat cuts decreased with decrease in feed level. The ratio of belly and cutting fat to ham and loin as an index of fatness [7] also decreased with the lowering of feed level.

TABLE 12.—*Comparison of average percentage yield of cuts in carcasses of hogs fed at different levels on corn and on wheat*

| Experiment and basal feed | Feeding level | Hogs | Cold carcass weight | Yield of— | | | | | | | Ratio of belly and cutting fat to ham and loin |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Shoulder | Ham | Trimmed loin | Back fat | Belly | Miscellaneous parts | Cutting fat | |
| | | *Number* | *Pounds* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *1:* |
| E, corn | High | 5 | 150.7 | 16.5 | 20.1 | 14.0 | 7.8 | 12.0 | 23.0 | 14.4 | 0.774 |
| | Medium | 5 | 150.4 | 16.4 | 20.7 | 14.5 | 7.1 | 11.6 | 22.9 | 13.9 | .724 |
| | Low | 5 | 149.1 | 17.4 | 21.1 | 15.6 | 6.0 | 11.1 | 23.2 | 11.6 | .620 |
| F, wheat | High | 6 | 152.2 | 17.5 | 19.4 | 14.4 | 8.4 | 11.4 | 20.3 | 16.7 | .831 |
| | Medium | 6 | 148.8 | 18.2 | 20.3 | 14.3 | 8.2 | 12.0 | 19.5 | 15.7 | .801 |
| | Low | 6 | 146.8 | 18.3 | 21.3 | 15.2 | 6.4 | 10.6 | 21.8 | 12.8 | .641 |
| | Self-fed | 6 | 149.7 | 17.4 | 19.2 | 13.8 | 9.2 | 12.1 | 20.5 | 17.0 | .882 |

An analysis of the variance (*4, p. 194*) within the lots in relation to that between lots for (1) the yield of the fat cuts and (2) the total yield of ham and loin showed that the feeding level had a significant effect on the yields of fat and lean cuts as judged by the odds of a chance observation. The value of $z$ for the variance in the yield of fat falls (table 13) between the 5-percent and 1-percent values of the

[7] WARNER, K. F., ELLIS, N. R., and HOWE, P. E. See footnote 5.

$z$ table and indicates odds of significance greater than 49 to 1. The $z$ value for the yield of ham and loin is even higher than that for the 1-percent value with odds greater than 99 ot 1.

TABLE 13.—*Difference of variance in yield of (1) fat and of (2) ham and loin of percentage cutting yields in experiment E (corn ration)*

| Item | Degrees of freedom | Sum of squares | Mean square | Standard deviation | Log standard deviation |
|---|---|---|---|---|---|
| Yield of fat: | | *Percent* | *Percent* | *Percent* | *Percent* |
| Between lots | 2 | 22.6295 | 11.3148 | 3.364 | 1.2131 |
| Within lots | 12 | 26.0000 | 2.1667 | 1.472 | .3866 |
| Total difference | 14 | 48.6295 | | | [1](z=).8265 |
| Yield of ham and loin: | | | | | |
| Between lots | 2 | 17.5575 | 8.7787 | 2.963 | 1.086 |
| Within lots | 12 | 7.7600 | .6467 | .804 | −.218 |
| Total difference | 14 | 25.3175 | | | [1](z=)1.304 |

[1] From Fisher's $z$ table (4): For 5 percent (odds 1:19), $z=0.6786$, and for 1 percent (odds 1:99), $z=0.9677$.

Table 14 shows the percentage of water, protein, fat, and ash in the edible and inedible parts of the bodies of the animals. The ham was separated into lean and fat and these parts analyzed separately. The composition of the total edible ham meat was then calculated. An additional series of calculated results was obtained by the combination of all the edible-meat fractions as the total edible portion of the carcass.

TABLE 14.—*Comparison of the average percentage chemical composition of body parts of the hogs in experiment E (corn ration) on 3 levels of feed*

| Body part | High level | | | | Medium level | | | | Low level | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Water | Protein | Fat | Ash | Water | Protein | Fat | Ash | Water | Protein | Fat | Ash |
| Edible parts: | | | | | | | | | | | | |
| Ham, lean | 72.32 | 20.35 | 6.22 | 1.08 | 72.50 | 20.29 | 5.97 | 1.02 | 73.76 | 21.09 | 4.64 | 1.11 |
| Ham, edible | 55.53 | 15.76 | 27.90 | .79 | 56.30 | 15.84 | 27.01 | .76 | 60.57 | 17.40 | 21.78 | .90 |
| Loin | 55.52 | 16.46 | 27.37 | .83 | 56.62 | 16.81 | 25.85 | .89 | 56.27 | 17.88 | 24.69 | .83 |
| Back fat | 7.64 | 1.93 | 90.44 | .12 | 8.60 | 2.06 | 89.91 | .13 | 10.03 | 3.06 | 87.41 | .14 |
| Remaining edible | 39.86 | 11.06 | 48.65 | .48 | 39.90 | 11.13 | 48.42 | .63 | 45.56 | 12.82 | 41.39 | .81 |
| Total edible | 42.31 | 11.91 | 45.46 | .56 | 43.54 | 12.30 | 43.60 | .67 | 48.45 | 14.04 | 37.15 | .77 |
| Inedible parts: | | | | | | | | | | | | |
| Skin | 40.30 | 25.81 | 34.40 | .72 | 40.62 | 24.82 | 35.39 | .59 | 45.17 | 26.80 | 28.76 | .55 |
| Bone | 43.20 | 18.99 | 13.87 | 22.38 | 41.33 | 18.91 | 14.99 | 23.51 | 41.17 | 20.10 | 14.68 | 22.88 |
| Viscera | 60.92 | 14.74 | 21.86 | 1.06 | 60.10 | 14.70 | 23.13 | 1.02 | 71.12 | 12.16 | 14.62 | .89 |
| Blood | 79.16 | 20.25 | .09 | 1.02 | 79.30 | 20.12 | .08 | .94 | 79.21 | 20.26 | .07 | .96 |

The protein content (nitrogen times 6.25) of the meat samples, both fat and lean, showed a generally consistent increase from the high level of feeding to the low level, just as there was an increasing yield of lean cuts. On the other hand, the fat content of the meat cuts decreased as the protein content increased. The total edible meat from the high-level and low-level lots differed in fat content by 8.31 percent and from the medium-level and low-level lots by 6.45 percent. A statistical analysis of the differences between the mean of the high- and low-level lots and of the medium- and low-level lots gave $P$ values of less than 0.01, which indicates significantly less

fat in the low-level lot than in either of the other two lots. However, there is no significant difference between the lots on the high and medium levels of feeding. The composition of the skin, bone, blood, and viscera appears to bear no relation to the feed level since no consistent differences between lots were observed.

The total percentage yields of mechanically separable fractions of the carcass, together with the average chemical composition of the entire bodies, are given in table 15. There were only small differences between lots in the average quantity of bone and skin. Hog 69 in the low-level lot yielded more bone than any other hog, and chemical analyses later showed that this hog had the highest ash content of all 15 hogs.

TABLE 15.—*Comparison of the physical and chemical composition of the entire bodies of hogs in experiment E (corn ration) on the 3 levels of feed*

| Feeding level | Hog no. | Weight of hog | | Physical composition of parts analyzed [1] | | | | | | Chemical composition | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Close of experiment | Parts analyzed | Blood | Viscera | Skin | Bone | Edible meat | | Water | Protein | Fat | Ash |
| | | | | | | | | Lean | Fat | | | | |
| | | *Lb.* | *Lb.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| High (4 percent of live weight) | 55 | 198 | 174.2 | 4.3 | 12.4 | 6.9 | 14.4 | 34.0 | 26.7 | 49.45 | 15.15 | 31.25 | 3.61 |
| | 56 | 205 | 190.2 | 3.4 | 10.8 | 4.6 | 12.3 | 34.1 | 30.7 | 49.68 | 14.62 | 33.25 | 3.26 |
| | 57 | 199 | 183.8 | 3.5 | 12.0 | 5.8 | 13.1 | 33.2 | 28.7 | 48.26 | 15.53 | 32.00 | 3.65 |
| | 58 | 194 | 177.7 | 3.1 | 10.1 | 5.9 | 13.6 | 35.0 | 29.6 | 45.75 | 14.68 | 36.52 | 3.64 |
| | 60 | 198 | 185.3 | 3.2 | 9.4 | 5.7 | 12.0 | 32.0 | 35.3 | 41.23 | 13.37 | 42.77 | 3.25 |
| Average | | 198.8 | 182.2 | 3.5 | 10.94 | 5.78 | 13.08 | 33.65 | 30.20 | 46.87 | 14.67 | 35.16 | 3.48 |
| Medium (3 percent of live weight) | 61 | 190 | 173.2 | 3.7 | 11.2 | 6.8 | 13.4 | 38.0 | 24.4 | 49.38 | 15.78 | 31.12 | 3.80 |
| | 62 | 200 | 182.0 | 3.9 | 11.5 | 4.6 | 12.3 | 31.8 | 32.3 | 46.27 | 13.85 | 35.94 | 3.46 |
| | 63 | 197 | 178.1 | 3.8 | 11.8 | 6.0 | 14.8 | 34.1 | 26.7 | 46.25 | 14.65 | 34.28 | 4.26 |
| | 64 | 203 | 190.0 | 3.3 | 10.5 | 5.7 | 12.7 | 35.6 | 29.4 | 48.04 | 14.97 | 33.52 | 3.70 |
| | 65 | 210 | 192.1 | 3.6 | 11.4 | 5.5 | 13.6 | 33.2 | 29.9 | 46.34 | 14.27 | 35.75 | 3.70 |
| Average | | 200.0 | 183.1 | 3.65 | 11.28 | 5.72 | 13.36 | 34.54 | 28.54 | 47.26 | 14.70 | 34.12 | 3.78 |
| Low (2 percent of live weight) | 66 | 196 | 176.4 | 3.7 | 10.7 | 4.9 | 12.5 | 40.9 | 24.7 | 50.60 | 15.82 | 30.30 | 3.38 |
| | 67 | 204 | 185.3 | 3.2 | 11.1 | 5.2 | 13.0 | 40.4 | 24.7 | 51.82 | 15.78 | 28.87 | 3.63 |
| | 68 | 197 | 177.7 | 3.7 | 10.7 | 5.7 | 13.4 | 37.6 | 26.3 | 50.83 | 15.52 | 29.73 | 3.68 |
| | 69 | 197 | 173.0 | 3.9 | 10.7 | 6.5 | 16.5 | 41.6 | 17.5 | 53.35 | 17.17 | 25.43 | 4.62 |
| | 70 | 198 | 187.9 | 3.6 | 11.4 | 5.7 | 12.4 | 39.8 | 24.6 | 51.65 | 15.05 | 29.93 | 3.55 |
| Average | | 198.5 | 180.1 | 3.62 | 10.92 | 5.60 | 13.56 | 40.06 | 23.56 | 51.65 | 15.87 | 28.88 | 3.77 |

[1] The hair and hoofs included in parts analyzed, but not listed, varied from 0.5 to 0.75 percent and averaged for lot 1, 0.63 percent; for lot 2, 0.65 percent; and for lot 3, 0.7 percent. The evaporation from the carcasses during chilling constitutes the remaining difference between 100 percent and the sum of parts listed including hair and hoofs..

The lots on the high and medium levels of feeding differed very little in yields of lean and of fat. However, the low-level lot yielded approximately 16 percent more lean meat and 17 percent less fat than the medium-level lot. In only one case the percentage of lean meat in the medium-level lot exceeded the lowest percentage among the hogs in the low-level lot, whereas the lowest percentage of fat in the medium-level lot was exceeded once in the low-level lot.

Just as in comparisons of physical and chemical analyses, there were no pronounced differences in chemical composition between the high- and medium-level lots. The hogs in the former lot, however, had relatively wide extremes in percentages of fat, which ranged from 31.25 to 42.77.

The hogs on the lowest feed level contained less fat and more lean than either of the other two lots. The *t* test of Fisher for significance of differences between the lots on the highest and the lowest levels of feeding, as well as between the lots on the medium and lowest levels, again showed *P* values of 0.01 or less. It appears reasonably certain that the limitation of the ration to 2 pounds for each 100 pounds of live weight produced significantly less fat in the body as a whole than either the 3-pound or 4-pound ration.

### WHEAT AS THE BASAL FEED

The physical and chemical analyses of the hogs on the wheat ration (experiment F) yielded results generally comparable to those of the preceding experiment. The comparisons of the yields of cuts are included in table 12. The group of hogs which were self-fed had the lowest percentage of lean cuts and the highest percentage of fat cuts of the four lots. The data show the same order of increase in lean and decrease in fat with change in feed level found on the corn ration. The differences between lots are also of a comparable order of significance to those already described.

The chemical analyses of the edible meat of each carcass from the hogs on the 4-, 3-, and 2-percent feeding levels are given in table 16. Analyses are given on 2 lean cuts, the ham and loin, and on 2 fat cuts, the belly and back fat. The lean meat of the ham was the only sample which did not show a marked change in fat content as the feed level decreased. The lot on the medium level of feeding yielded results midway to those of the other 2 lots and indicated that the reduction in feed level from 4 to 3 percent of the live weight of the animal had a greater effect on composition of the meat than a similar reduction on the corn ration. The differences in fat content of the total edible meat was 10.83 percent between the high- and low-level lots and 7 percent between the medium- and low-level lots. The fat content of the meat of the low-level lot was reduced to approximately 76 percent of that of the lot on the high level of feeding. A statistical examination of the differences of the means for fat and for protein content showed that a significant difference existed between the lots on the high and medium levels of feeding, on the medium and low levels, and on the high and low levels. The essential point of difference from experiment E was in the more pronounced reduction in fat content in the medium-level lot.

TABLE 16.—*Comparison of the average chemical composition (percent) of edible portions of pork cuts of the hogs in experiment F on 3 levels of the wheat ration*

| Pork cut | High level | | | | Medium level | | | | Low level | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Water | Protein | Fat | Ash | Water | Protein | Fat | Ash | Water | Protein | Fat | Ash |
| Ham, lean | 73.60 | 19.55 | 5.85 | 1.06 | 72.84 | 20.32 | 5.96 | 1.02 | 73.30 | 20.48 | 5.47 | 1.04 |
| Ham, edible | 55.89 | 14.98 | 28.33 | .80 | 58.01 | 16.27 | 24.83 | .81 | 61.78 | 17.73 | 20.24 | .87 |
| Loin | 56.38 | 15.21 | 27.40 | .79 | 58.94 | 16.67 | 23.77 | .80 | 61.64 | 17.93 | 19.86 | .87 |
| Back fat | 8.53 | 2.46 | 88.36 | .18 | 10.44 | 2.82 | 85.98 | .16 | 11.31 | 3.08 | 85.10 | .25 |
| Belly | 35.58 | 9.57 | 54.44 | .61 | 38.27 | 10.37 | 50.62 | .53 | 41.77 | 11.12 | 46.57 | .56 |
| Remaining edible | 41.62 | 10.60 | 47.09 | .61 | 44.61 | 11.44 | 43.03 | .59 | 49.10 | 12.90 | 37.08 | .69 |
| Total edible | 42.60 | 11.22 | 45.49 | .63 | 45.28 | 12.23 | 41.66 | .61 | 50.73 | 13.88 | 34.66 | .72 |

### EFFECTS OF FEEDING LEVEL ON FIRMNESS OF FAT, PALATABILITY, AND OTHER QUALITY FACTORS

One of the factors which contribute to the quality of pork is the firmness of the fat tissues. Peanuts generally produce a soft or oily fat when they are fed to hogs for extended periods. The seven hogs killed at the conclusion of the peanut-feeding period in experiments A and B graded soft, and analyses of the fat showed the usual fat constant values found under such conditions. No marked differences were noted between the three hogs on full feed and the four hogs on the low feeding levels.

The firmness gradings of the six hogs in experiment D fed a corn ration and slaughtered at weights of 183 to 200 pounds were hard for two hogs and medium hard for one hog in the full-fed group, and hard for one hog and medium hard for two hogs in the group fed at the 60-percent level. The average refractive-index readings on the back fat were 1.4593 and 1.4595 respectively for the two groups.

A ration of corn with nonsoftening supplements fed to hogs until their weights approximate 200 pounds usually produces firm carcasses when the hogs are full fed or self-fed. The results given in table 17 indicate that the carcasses in experiment E were less firm than the usual average. Two of the carcasses of the lot on the 4-percent feed level were medium soft. Decreases in fed allowance were associated with increased softness in the carcasses. Those carcasses with the thickest back-fat layer were usually the firmest.

TABLE 17.—*Comparison of the firmness, fat analyses, and fat-layer measurements of the carcasses of the hogs in experiment E (corn rations)*

| Feeding level | Hog no. | Slaughter weight | Firmness of carcass | Back fat | | |
|---|---|---|---|---|---|---|
| | | | | Refractive index 40° C. | Iodine no. | Thickness |
| | | *Pounds* | | | | *Millimeters* |
| High | 55 | 188 | Medium soft | 1.4599 | 68.6 | 25 |
| | 56 | 195 | Medium hard | 1.4597 | 65.8 | 36 |
| | 57 | 190 | Medium soft | 1.4598 | 68.2 | 26 |
| | 58 | 190 | Medium hard | 1.4594 | 64.2 | 35 |
| | 59 | 220 | do | 1.4594 | 65.4 | 32 |
| | 60 | 193 | Hard | 1.4593 | 64.3 | 42 |
| | Average | 196 | | 1.4596 | 66.1 | 32 |
| Medium | 61 | 190 | Medium soft | 1.4600 | 70.3 | 29 |
| | 62 | 191 | Medium hard | 1.4596 | 65.2 | 32 |
| | 63 | 193 | Medium soft | 1.4598 | 67.6 | 30 |
| | 64 | 203 | Medium hard | 1.4598 | 69.7 | 38 |
| | 65 | 204 | do | 1.4594 | 65.4 | 31 |
| | Average | 196 | | 1.4597 | 67.6 | 32 |
| Low | 66 | 190 | Medium soft | 1.4602 | 73.3 | 26 |
| | 67 | 200 | do | 1.4601 | 70.1 | 32 |
| | 68 | 187 | do | 1.4600 | 69.9 | 28 |
| | 69 | 190 | Soft | 1.4605 | 75.9 | 24 |
| | 70 | 203 | Medium soft | 1.4600 | 69.8 | 29 |
| | 71 | 195 | do | 1.4601 | 70.8 | 34 |
| | Average | 194 | | 1.4602 | 71.6 | 29 |

Both the refractive-index and the iodine-number values showed a definite increase in unsaturation of the body fat with decrease in feed level. The changes in saturation of the fat indicated that the decrease in total fat stored was largely at the expense of the saturated

acids such as palmitic and stearic. These acids generally occur in relatively small proportions in the oils contained in the usual hog feeds and when built into body fat in the hog are largely the product of synthesis. Although the intake of the unsaturated acids was greatly reduced by the restriction in feed intake of this experiment, the proportion of these acids in the total fat actually stored was increased. Of the two possible sources available, namely, synthesis or use of ingested fatty acids, the greater reduction apparently occurred in the former source.

A marked difference in finish occurred in the three lots in experiment E as judged by yields of lean and fat meat, fat content of the carcasses, and thickness of the back fat. Increasing firmness of hogs fed on rations of corn with nonsoftening supplements has been found to be related to weight, which in turn is generally associated with the finish or fatness (7). With weight held constant in experiment E, the firmness was related to the finish.

The results relating to the firmness of the hogs receiving wheat as the basal feed (experiment F) are given in table 18. All hogs on the 4-percent feed level were graded hard, whereas in the self-fed lot only three out of six were graded hard. The differences in the fat constants between lots were small. Apparently, the feed level had little if any effect on the firmness of the carcass. The relationship noted in experiment E between the thickness of the back-fat layer as an expression of finish and the firmness was also negligible.

TABLE 18.—*Comparison of the firmness, fat analyses, and fat-layer measurements of the carcasses of hogs in experiment F (wheat rations)*

| Feeding level | Hog no. | Slaughter weight | Firmness of carcass | Back fat | | |
|---|---|---|---|---|---|---|
| | | | | Refractive index 40° C. | Iodine no. | Thickness |
| | | *Pounds* | | | | *Millimeters* |
| High | 72 | 187 | Hard | 1.4584 | 56.6 | 31 |
| | 73 | 203 | do | 1.4589 | 58.4 | 39 |
| | 74 | 203 | do | 1.4584 | 55.2 | 44 |
| | 75 | 193 | do | 1.4584 | 56.9 | 35 |
| | 76 | 200 | do | 1.4587 | 58.4 | 35 |
| | 77 | 190 | do | 1.4584 | 57.7 | 36 |
| | Average | 196 | | 1.4585 | 57.2 | 36.6 |
| Medium | 78 | 190 | Hard | 1.4588 | 58.4 | 32 |
| | 79 | 199 | Medium hard | 1.4588 | 60.1 | 36 |
| | 80 | 195 | Hard | 1.4584 | 54.2 | 37 |
| | 81 | 194 | do | 1.4585 | 57.5 | 36 |
| | 82 | 188 | do | 1.4586 | 58.6 | 36 |
| | 83 | 189 | Medium hard | 1.4587 | 57.5 | 33 |
| | Average | 192.5 | | 1.4586 | 57.7 | 35.1 |
| Low | 84 | 196 | Hard | 1.4587 | 57.9 | 25 |
| | 85 | 190 | do | 1.4588 | 57.9 | 30 |
| | 86 | 190 | do | 1.4584 | 54.9 | 32 |
| | 87 | 191 | Medium hard | 1.4588 | 58.2 | 26 |
| | 88 | 190 | Hard | 1.4586 | 56.3 | 28 |
| | 89 | 196 | Medium hard | 1.4592 | 60.4 | 27 |
| | Average | 192 | | 1.4588 | 57.6 | 27.9 |
| Self-fed | 90 | 191 | Hard | 1.4587 | 58.7 | 48 |
| | 91 | 194 | Medium hard | 1.4591 | 59.5 | 37 |
| | 92 | 193 | Hard | 1.4585 | 55.1 | 38 |
| | 93 | 192 | do | 1.4587 | 57.8 | 42 |
| | 94 | 201 | Medium hard | 1.4590 | 59.4 | 41 |
| | 95 | 190 | Medium soft | 1.4592 | 62.5 | 30 |
| | Average | 193.5 | | 1.4589 | 58.5 | 39.5 |

The cooking and palatability tests carried out according to the procedure used in cooperative meat investigations [8] were made on uncured hams from hogs on the high and low levels of feeding in experiments E and F. The average results are given in table 19. Comparison of the two lots in each experiment shows that the feed level failed to produce any marked differences in the factors of quality.

TABLE 19.—*Comparison of the total cooking loss and palatability* [1] *of half-ham samples from experiments E and F*

| Feeding level | Hogs studied | Cooking loss | | Aroma | | Texture | Flavor of fat | | Flavor of lean | | Tenderness | Juice | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Evaporation | Drippings | Intensity | Desirability | | Intensity | Desirability | Intensity | Desirability | | Quality | Quantity |
| | *No.* | *Per cent* | *Per cent* | | | | | | | | | | |
| **EXPERIMENT E (CORN AS BASAL FEED)** | | | | | | | | | | | | | |
| High | 5 | 18.1 | 10.8 | [2] 5.1 | [3] 4.9 | [4] 4.6 | [3] 4.6 | [3] 5.4 | [3] 5.0 | [3] 5.0 | [5] 4.6 | [6] 4.2 | [7] 4.2 |
| Low | 4 | 18.0 | 9.5 | [2] 5.4 | [3] 4.7 | [4] 4.8 | [3] 4.5 | [3] 5.0 | [3] 4.6 | [3] 4.9 | [5] 4.4 | [6] 3.9 | [7] 3.7 |
| **EXPERIMENT F (WHEAT AS BASAL FEED)** | | | | | | | | | | | | | |
| High | 6 | 19.7 | 10.6 | [2] 4.7 | [3] 5.2 | [4] 5.3 | [8] 3.7 | [3] 4.7 | [9] 4.2 | [3] 4.9 | [5] 4.7 | [6] 3.9 | [7] 4.1 |
| Low | 6 | 21.0 | 11.1 | [2] 5.1 | [3] 4.9 | [4] 4.9 | [8] 3.6 | [3] 5.1 | [2] 4.5 | [3] 5.1 | [5] 4.6 | [6] 3.8 | [7] 3.5 |

[1] Palatability as determined by cooked-meat grading committee. Maximum score for each item is 7.
[2] Moderately pronounced.
[3] Moderately desirable.
[4] Moderately fine.
[5] Moderately tender.
[6] Slightly rich.
[7] Slightly dry.
[8] Slightly tough.
[9] Slightly pronounced.

Only a slight decrease occurred in the lots on the low-feeding level in both experiments in desirability of aroma, in intensity of flavor of fat, in tenderness, and in quality or richness of juice. In texture and in desirability of flavor of fat and lean, the differences between lots in one experiment were at variance with those of the other. The greatest difference between lots was observed in the quantity of juice; the low-feeding level apparently produced the drier meat when cooked.

With respect to cooking losses, the differences between lots both in evaporation and drippings (table 19) were neither consistent between experiments nor of sufficient size to offer an explanation for the differences in quantity of juice. The slightly higher percentage of drippings in the low level as compared with the high-level lot of experiment F was contrary to normal expectation, on the basis of fat content by analysis, and also contrary to results obtained for drippings in experiment E.

The fat content of the lean meat of the hams (tables 14 and 16) was not greatly affected by feeding level and may have been responsible in part for the slight differences in palatability and cooking losses.

[8] UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF HOME ECONOMICS AND ANIMAL INDUSTRY. METHODS OF COOKING AND TESTING MEAT FOR PALATABILITY. 36 pp. Revised, February 1933. [Mimeographed.]

## DISCUSSION

The feeding results obtained with peanuts, corn, and wheat as the basal feeds have generally agreed in the increased economy of gain resulting from reductions in feed allowance to the hogs. The feeding levels used in the different rations varied somewhat, owing chiefly to the nature of the ration. Thus, the peanut rations, with their high oil content, were not consumed at the same weight level on a full-feed basis although they were usually consumed at a higher caloric level than the corn and wheat rations. The results of experiments A, B, and C with the peanut rations suggested that the medium level afforded the most economical utilization of feed. Although further reduction of feed to approximately one half of a full feed caused a slight increase in feed requirements, it was not sufficient to be judged significant.

Experiment D, with the corn ration, showed increased economy when the feed level was reduced 40 percent from that of the full-fed lot. The average results of experiment E, also with the corn ration, showed that the saving in feed by reduction from the 4 to 3-percent level was not greatly different from the saving obtained by further reduction from 3 to 2 percent. On the other hand, no further saving was effected on the wheat ration (experiment F) by the reduction in feed level from 3 to 2 percent. The poor gains of the lot on the lowest level during the early part of the experiment and the consequent lengthening in the time required to reach a final weight of 200 pounds are the main points of difference in the reaction of the lot to the wheat ration and the reaction of the corresponding lot in experiment E to the corn ration.

Most of the initial weights in all the experiments were within the range of 55 to 80 pounds. The work with peanuts did not permit the continuation of the restricted feeding much beyond a weight of 135 pounds. Since the feeding level on a full or limited basis of the growing animal during the early period of growth is generally higher than during the later period as maturity approaches, the more severe effects of feed restriction are likely to be felt during the early growth period.

It is apparent that further decreases in the feed allowance below the quantities given in these experiments would eventually lead to increasing requirements for unit gains. That a 50-percent reduction in the feed allowance below the full level should result in better utilization and lowered feed requirements per unit of gain even when the rate of gain is reduced is undoubtedly a contradiction of the general opinion as shown in the references previously quoted.

The rations were not unusual in composition. The peanut rations contained more protein than the corn or wheat rations. In experiment E with the corn ration, the daily protein intake of the six hogs on the low level of feeding at 100-pound weights was approximately 0.3 pound. This quantity is little more than half that given in feeding standards. Whether the protein, the total energy derived from the feed, or other dietary constituents limited the development of the animal remains for future experiments to determine.

The vigor and thriftiness of the pigs were undoubtedly factors in the efficient utilization of feed on the limited feed levels, not that the pigs were exceptional in this respect but rather that unthrifty pigs could not be expected to respond efficiently at reduced feed levels.

One example of such abnormality was furnished in experiment C when pigs at the three levels under test failed to gain at a reasonable rate during the first 3 weeks of the experiment. Information from group-feeding experiments had indicated that individual feeding was not an important factor but it served to insure a definite quantity of feed to each pig at each feeding and thus prevented wide variations in feed consumption and rate of growth likely to occur in group feeding.

The pronounced saving in feed effected by restriction of the feed level on the peanut and corn rations and also the small saving on the wheat ration can be explained only by a more efficient utilization of the feed constituents and a decrease in the quantity of fat stored in the body tissues. The data suggest that the initial increases in economy of gains, particularly on the medium level, on the various rations were due to increased efficiency in utilization. Undoubtedly a lower percentage of the nutrients in mixed rations may be assimilated by heavily fed animals than by moderately fed animals. Other workers (*1*, *5*, *14*) have recognized that plane of nutrition is a factor in the evaluation of the efficiency of utilization.

Because of their high oil content, the peanut rations are particularly susceptible to a relatively low efficiency in digestion and assimilation of the food constituents on a high feeding level. The overtaxing of the digestive and assimilative processes of the body may have been sufficiently relieved by the lowered intake to permit of more efficient utilization. Although a peanut ration has approximately a 50-percent higher caloric value than that of a corn ration, the intake in calories in the five lots in experiments A, B, and C on low and medium levels was below the estimates for a normal intake of a corn ration. This would indicate that more efficient conversion of food constituents into body constituents occurred rather than a difference in the proportions of fat and protein storage.

The building of fatty tissue requires a greater expenditure of food constituents (fat excepted) than the building of lean tissue. The limitation of the peanut rations to approximately a half feed did not materially decrease the storage of fat in the bodies of the hogs analyzed. If the energy required had been the limiting factor the ingested fat would have been used for this purpose and a greatly decreased rate of fat storage should have resulted. Apparently this did not occur, judging by the results given in table 11.

Although the hogs on the reduced feed levels in experiments E and F apparently utilized their feed somewhat more efficiently than those on the high level, much of the saving in feed was made at the expense of the fat storage. From table 15 it can be determined that the hogs on the 2-percent level of experiment E stored approximately 12 pounds less fat than those on the 4-percent level. A similar difference between the lots on the corresponding feed levels is indicated in experiment F. The longer period of growth on the reduced feed levels, with the consequent greater quantity of feed used for maintenance, makes difficult even an approximation of the saving in feed due to decreased fat storage and to greater efficiency in utilization. The feed expended for maintenance by the lot of hogs on the 2-percent level in experiment F due to their slow rate of growth (table 9) undoubtedly dissipated much of the possible saving of feed otherwise effected by decrease in fat storage and by other increases in efficiency of utilization.

Recent experimental work on paired feeding has shown the importance of controlled feeding. The present work has gone one step beyond the paired method in that different levels of feeding have been employed. The hogs within a given group were usually fed the same daily allowance. In experiments E and F this allowance was based on a certain percentage of the weights of the hogs, namely 4, 3, and 2 percent. The high level represented a full feed in the usual case. This method furnished a convenient way for describing the exact allowance to be used. If differences in feed allowance result in marked differences in the relationship between feed consumption and gain in weight, as occurred in these experiments, then comparisons of feeds and of rations need to be made at definite and stated levels of feed intake.

Thus one ration may be markedly superior to others but may not show its value because it is consumed in larger quantities with consequent decrease in efficiency of utilization. It must not be overlooked that in many experiments reported in the literature the hogs have actually made improved rates of gain along with increased savings in feed requirements per unit gain when an improvement in the palatability of the ration has resulted in increased consumption. Frequently this improvement has been brought about by incorporation of a supplement supplying a certain substance or group of substances lacking in the ration in question. Improvement in the health and vigor of the animal brings with it increased appetite. The wide variation among growing animals of a given species, even though of the same age and sex and under the same environment, in their ability to consume feed and to convert feed into body constituents, has been a primary factor contributing toward the observed differences in the feed lot.

It must be recognized that the restriction of the feed allowance in the present experiments is not entirely comparable to the self-imposed restriction of one self-fed hog of small appetite, as compared with the greater consumption by a second hog similarly fed but with a better appetite and greater ability to assimilate the feed constituents. The combination of factors responsible for the association of increased efficiency of feed utilization and increased rate of growth in the latter case of unrestricted feeding may be different and less involved than the combination of factors in the limitation of the daily feed allowance. One distinction, at least, concerns the individual ability of the animals regardless of the quantity of feed consumed as contrasted with the general relationship between quantity of feed and efficiency of assimilation.

The effect of restriction of feed on the decreased proportion of fat in the carcass observed in experiments E and F is an important factor in the field of meat production. Present-day demands of the meat-consuming public are for lean cuts rather than for fat cuts. Because degree of finish or fatness of the hog carcass in the usual case is largely a question of weight, the 175- to 200-pound hog usually sells for a higher price per pound than the 250- to 300-pound hog. The fact that the rate of fattening was checked by limitation of the feed appears worthy of consideration in the development of feeding methods to meet the market demands for meat. Cooking and palatability tests on hams from these lots did not reveal any noteworthy differences. However, the carcasses of the hogs fed corn had a somewhat less

desirable degree of firmness in the lot on the low feeding level than in the other lots. The use of wheat apparently eliminated the possible softening effect of the feed level.

The differences observed in the response to reduction in feed level of peanuts, corn, and wheat suggest that the composition of the ration is a factor. The need is at once apparent for an adequate supply of the essential mineral elements, proper proteins, vitamins, and other factors essential to the well-being of the animal. Other properties more particularly concerned with the digestibility of the feed constituents may play a part.

The application of reduced feed levels to practical feed-lot and market conditions remains to be determined. Necessarily, the savings in feed will vary with the kind and choice of feeds in the ration, the thriftiness of the hogs, and how well the feeder can control the feed allowance under group-feeding conditions. It is altogether possible that the increased labor charge and other undesirable factors associated with the lengthened feeding period more than offset the saving in feed shown in the present experiments.

## SUMMARY

Restriction of the feed allowance of growing pigs to approximately three fourths and one half of a full feed generally decreased the quantity of feed required to produce a unit of gain.

On peanut rations the best gains were produced on a three-fourths allowance. Although the feed requirements for a unit of gain were the lowest on this level, the differences between these requirements and those on the low level were not significant.

Hogs fed a ration of corn with supplements, at levels of 4, 3, and 2 pounds of feed per 100 pounds of live weight, gained from an initial weight of approximately 65 pounds to 200 pounds at rates of 1.14, 1.03, and 0.77 pounds per day, respectively. However, the feed consumption per unit gain showed a significant decrease with the decrease in feed level, and the group on the high-feed level required 34 percent more feed than the group on the low-feed level.

Results with a wheat ration fed under conditions comparable to those for the above-mentioned corn ration showed average daily gains of 1.26, 0.95, and 0.62 pounds with decrease in feed level. The feed consumption per unit gain was not decreased to the extent of that of the corn ration.

The carcasses of hogs on the most restricted feeding level of corn and of wheat contained a significantly greater proportion of lean meat and yielded a higher percentage of lean cuts. The fat content of the entire body was decreased as a result of the restriction of feed. No marked effect on the fatness of the body resulted from the restriction of the peanut rations to 50 percent of a full feed in the case of pigs fed for gains of from 50 to 60 pounds. Although the restricted feeding apparently resulted in a slight decrease in the firmness of the carcasses in the corn-fed lots, no significant differences in the palatability factors of the cooked meat were found in comparisons of the high and low feeding levels on both the corn and the wheat rations.

These results also indicate the influence of controlled feeding levels in comparative feeding experiments with hogs with respect to the effect of differences in intake of hogs on the efficiency of utilization of the ration.

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# YIELD OF SECOND-GROWTH WESTERN HEMLOCK-SITKA SPRUCE STANDS IN SOUTHEASTERN ALASKA

By R. F. TAYLOR

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## INTRODUCTION

The area known as southeastern Alaska is eminently suited for the continuous production of forest crops. Although it lies largely between 55° and 59° north latitude, which is approximately the latitude of Labrador, the area has a climate extremely favorable to forest growth, differing but little from that of the Puget Sound area. The mean temperatures for the winter months range from 29½° to 35° F., and those for the summer months from 50° to 55°. Precipitation is heavy, varying between approximately 80 inches at Juneau and 160 inches at Ketchikan, with no pronounced dry season.

The region includes a belt of mainland and numerous islands, shown in figure 1. These lands are rugged and mountainous. Virgin forests cover them almost completely to an elevation of 2,000 to 2,500 feet, commercial types extending to about 1,500 feet. Less than 1 percent of the land included in the area, it is estimated, is suitable for agriculture. Inasmuch as the area lies almost entirely within the Tongass National Forest, has excellent water-power resources, and offers facilities for cheap water transportation of forest products to mills and markets, conditions are ideal for the development of a large and permanent wood-using industry.

In general the forest land is occupied by virgin stands of mixed western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce (*Picea sitchensis* (Bong.) Carr.), with small percentages of Alaska cedar (*Chamaecyparis nootkatensis* (Lamb.) Spach) and, in the southern

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part, western red cedar (*Thuja plicata* D. Don). The volume of commercial timber is estimated to be approximately 78.5 billion board feet, Scribner rule, of which hemlock forms 74 percent, spruce 20 percent, and the two cedars 3 percent each. The stands of commercial quality average about 20,000 board feet per acre and are largely overmature. The volume per acre is too low for extensive

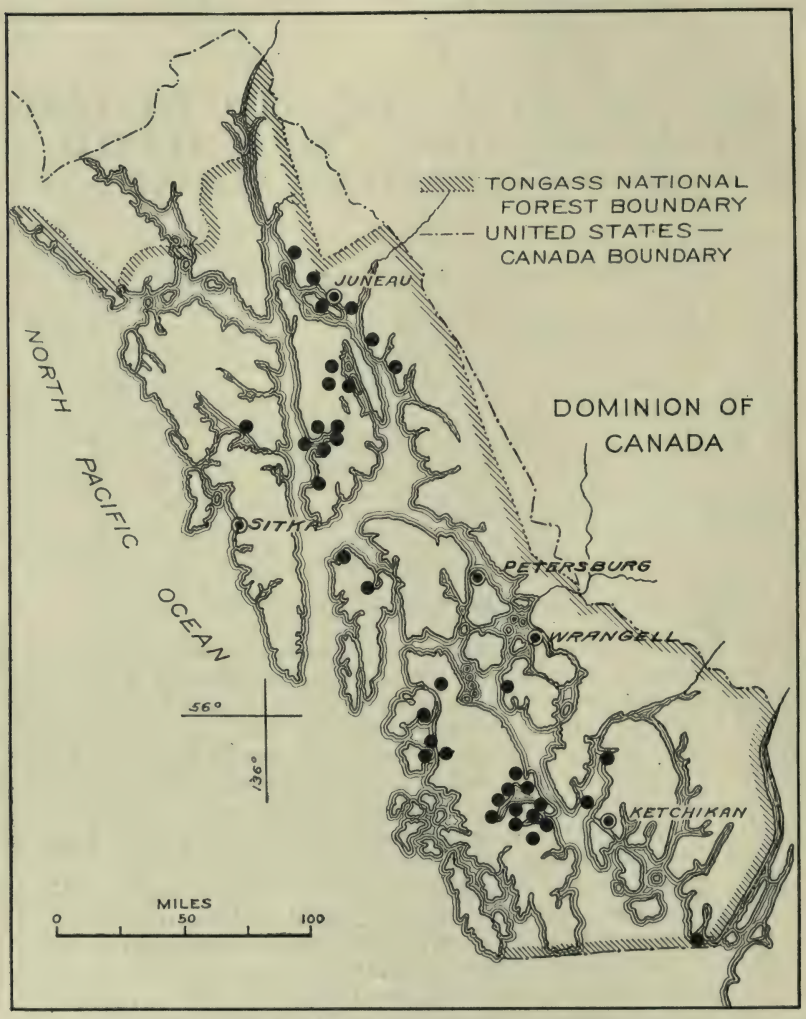


FIGURE 1.—Southeastern Alaska. Each black dot represents a locality where one or more sample plots were measured in the hemlock-spruce yield study.

sawmill logging except in small individual units containing 50,000 board feet or more per acre, but the volume, species, and quality are highly satisfactory for the manufacture of pulp and paper. Good silviculture requires that the climax forest now occupying the land be removed to make way for faster growing second-growth stands. The advent of wood-using industries would assure this cutting and make it possible to evolve plans for continuous forest management.

For the purpose of planning management in detail and allotting suitable areas to wood-using industries it is necessary to know, approximately at least, the producing power of individual areas. With this in mind, a study of growth and yield of even-aged normally stocked second-growth stands has been made, the results of which are presented here.

The data for the study were obtained on 288 sample plots, varying in size from one tenth to 1 acre, laid out in representative young forests. In general, each plot contained from 150 to 300 trees. Figure 1 shows the location of the forests sampled. Scarcity of young normally stocked stands made it difficult to sample conditions through the entire area; it will be noted that the central portion of the area is not well represented. Growing conditions over the area covered vary but little, however, and it is believed that the samples are adequately representative. On each tract sampled, plots were established on areas of different site quality.

## CHARACTERISTICS OF THE FOREST

The forests of southeastern Alaska are an extension of the coastal forests of Oregon, Washington, and British Columbia, with the difference that they lack some of the species found in the latter and consist predominantly of western hemlock and Sitka spruce. The climatic climax association, which occupies most of the forested land in the region, consists in an all-aged mixture of spruce and hemlock, with minor quantities of cedar, in which hemlock composes about 75 percent of the stand by volume. Within this general type are to be found variations due to local differences in climate, soil, and topography. This association, although better suited than any other to maintain itself indefinitely in southeastern Alaska, is not the most productive that can be grown there.

The relative proportions of spruce and hemlock in a stand are usually determined by soil conditions. Reproduction studies show that exposed mineral soils, soils rich in lime or nitrates, favor spruce survival. An undisturbed layer of raw humus and acid litter is unfavorable to spruce but often permits the development of dense thickets of pure hemlock, which stagnate at an early age and produce poor yields. Such thickets do not cover extensive areas, and pure stands of second-growth hemlock are not plentiful. Usually, second-growth stands contain from 10 to 75 percent spruce, by basal area, in mixture. Pure spruce stands are scarce except on lands recently uncovered by glacial recession or on landslide areas. Either species in pure stands has a low yield—hemlock from overstocking and consequent stagnation and spruce from the absence of the intermediate and lower crown classes, which makes for an open, parklike stand. Pure stands were excluded from this study, for the reason just given and because they are not typical.

A stand on the Tongass National Forest that is typical of second-growth timber in southeastern Alaska is shown in plate 1.

Almost any area in southeastern Alaska on which the mineral soil is exposed by a landslide, by glacier recession, or otherwise is reclothed naturally with tree species in a short period. Studies of the successional stages on recently glaciated land by Cooper (*3*) [1] have shown

[1] Italic numbers in parentheses refer to Literature Cited, p. 129.

Sitka spruce to be the first tree species following the alder-willow-poplar brush stage. Dense stands of pure spruce in even-aged belts become established in the paths of receding glaciers. Even-aged spruce stands likewise cover landslide areas. As the pure spruce stand nears maturity, an infiltration of the more shade-enduring hemlock begins (7). Hemlock gradually forms a larger and larger percentage of the stand, the even-aged character is lost, and eventually the climax is reached in which, as has been stated, the hemlock composes about 75 percent of the stand by volume.

Logging operations in the climax stands do not expose mineral soil to the same extent as glacier action and landslides. They throw the forest back several stages in the successional series, however, with the result that the percentage of spruce increases materially over that in the climax type. As spruce is preferred above hemlock in forest management for pulp-timber production, because of its more rapid growth and longer fiber, these new stands on cut-over areas will be superior to the climax stands now existing. The studies made to date indicate that the proportion of spruce in this second growth at the end of a rotation period of between 75 and 100 years will be about 50 percent.

## SITE INDEX

The site factors influencing the yield of these even-aged, second-growth stands are undoubtedly many and complicated. Site quality, the composite of these factors, is best expressed in terms of average height of the dominant trees. Average height of dominant trees, in feet, at a given age is customarily used as a "site index." In the present study site indices were taken at 100 years. They are shown in table 1 and figure 2, with the corresponding average heights of dominants at other ages.

TABLE 1.—*Average total height of dominant trees*

| Age | Average total height (in feet), by site index— | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 21 | 25 | 29 | 34 | 38 | 42 | 46 | 51 | 55 | 59 | 63 |
| 40 years | 26 | 31 | 37 | 42 | 47 | 53 | 58 | 64 | 69 | 74 | 79 |
| 50 years | 31 | 37 | 43 | 50 | 56 | 62 | 69 | 75 | 82 | 89 | 94 |
| 60 years | 35 | 42 | 49 | 57 | 64 | 71 | 79 | 86 | 93 | 100 | 107 |
| 70 years | 40 | 47 | 55 | 63 | 71 | 79 | 87 | 95 | 103 | 112 | 119 |
| 80 years | 43 | 52 | 61 | 69 | 78 | 87 | 95 | 105 | 113 | 122 | 131 |
| 90 years | 47 | 56 | 65 | 75 | 84 | 93 | 103 | 113 | 122 | 132 | 141 |
| 100 years | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 110 years | 53 | 64 | 74 | 85 | 95 | 106 | 117 | 128 | 138 | 149 | 160 |
| 120 years | 56 | 67 | 78 | 90 | 100 | 111 | 123 | 134 | 145 | 157 | 168 |
| 130 years | 58 | 70 | 81 | 94 | 105 | 116 | 128 | 140 | 152 | 164 | 176 |
| 140 years | 61 | 73 | 85 | 97 | 109 | 121 | 134 | 146 | 158 | 171 | 183 |
| 150 years | 63 | 76 | 88 | 101 | 114 | 126 | 139 | 152 | 164 | 177 | 190 |

For areas occupied by even-aged stands it is a simple matter to determine the site index. Ring counts are made by means of increment borings, and the total height of a dozen or more dominant trees is measured. For total age, an addition ranging from about 10 years on the poorest site to 5 years on the best is made to the average ring count at breast height. The average age and average height as thus determined are applied to table 1 or figure 2.

TYPICAL STAND OF SECOND-GROWTH TIMBER ON THE TONGASS NATIONAL FOREST, ALASKA.

Site index, 108 feet at 100 years. Age, 97 years. Total volume of stand, approximately 12,000 cubic feet per acre. Merchantable volume, approximately 11,000 cubic feet per acre.

## GROWTH DIFFERENCES OF SPRUCE AND HEMLOCK

Western hemlock does not attain the total height of Sitka spruce at maturity. In the young fast-growing stand, however, the proportion of hemlock actually has little influence on the average height of dominants. Separate height curves for hemlock and spruce on a given plot or group of plots in such stands are usually very close together.

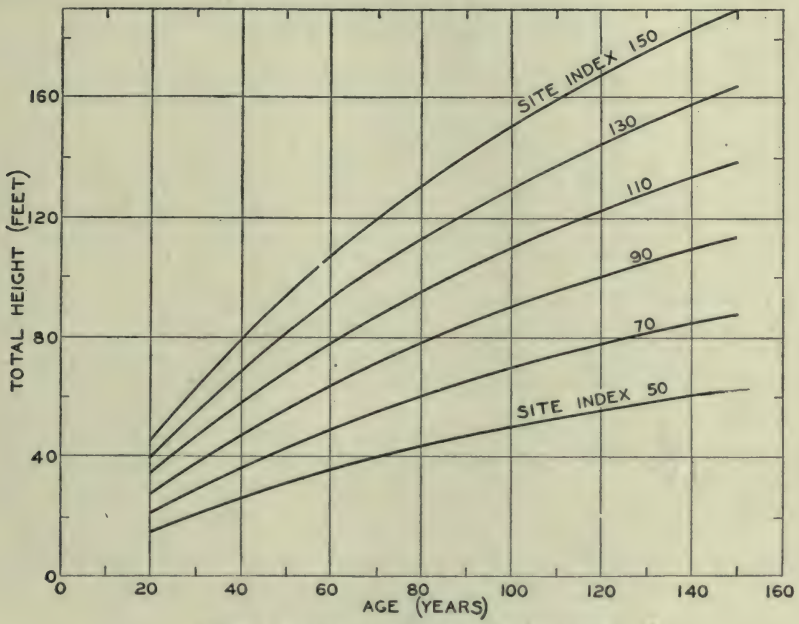


FIGURE 2.—Average total height of dominant trees.

Curves of average total height for second-growth spruce and hemlock over breast-height diameter show the two species to have slightly different trends of growth from early life to maturity (table 2). For trees less than 8 inches in breast-height diameter, the average heights of the two species seldom differ by more than 2 feet. At the 12-inch diameter hemlock definitely outstrips spruce in height growth, and at 18 inches it shows a maximum excess in height of 6 feet. The spruce outstrips the hemlock in height growth at the 24-inch diameter, and thereafter increases its lead.

TABLE 2.—*Average height of spruce and hemlock dominants* [1]

| Diameter at breast height | Total height of dominants | | Diameter at breast height | Total height of dominants | | Diameter at breast height | Total height of dominants | |
|---|---|---|---|---|---|---|---|---|
| | Spruce | Hemlock | | Spruce | Hemlock | | Spruce | Hemlock |
| | *Feet* | *Feet* | | *Feet* | *Feet* | | *Feet* | *Feet* |
| 8 inches | 66 | 66.0 | 16 inches | 104 | 110.0 | 24 inches | 135 | 134.5 |
| 10 inches | 77 | 77.0 | 18 inches | 112 | 118.0 | 26 inches | 141 | 139.0 |
| 12 inches | 86 | 89.0 | 20 inches | 120 | 124.5 | 28 inches | 147 | 143.5 |
| 14 inches | 95 | 100.5 | 22 inches | 128 | 130.0 | | | |

[1] Based on a composite curve of total height of dominants over their breast-height diameter, for 37 groups of plots representing a wide range of sites.

Analysis of the sample plots shows, however, that spruce dominants on a given plot average 6.9 percent larger in breast-height diameter than the associated hemlock dominants. The actual difference in the heights of the dominants of the two species, therefore, is more nearly as shown in table 3.

TABLE 3.—*Height of hemlock and spruce dominants on identical plots, by average diameter at breast height*

| Hemlock | | Spruce | | Difference in total height | Hemlock | | Spruce | | Difference in total height |
|---|---|---|---|---|---|---|---|---|---|
| Average diameter | Total height | Average diameter [1] | Total height | | Average diameter | Total height | Average diameter [1] | Total height | |
| *Inches* | *Feet* | *Inches* | *Feet* | *Feet* | *Inches* | *Feet* | *Inches* | *Feet* | *Feet* |
| 8 | 66.0 | 8.55 | 69.5 | 3.5 | 16 | 110.0 | 17.10 | 108.0 | 2.0 |
| 10 | 77.0 | 10.69 | 80.0 | 3.0 | 18 | 118.0 | 19.24 | 117.0 | 1.0 |
| 12 | 89.0 | 12.83 | 90.0 | 1.0 | 20 | 124.5 | 21.38 | 125.5 | 1.0 |
| 14 | 100.5 | 14.96 | 99.0 | 1.5 | 22 | 130.0 | 23.52 | 133.0 | 3.0 |

[1] Averages 6.9 percent greater than that of the hemlock.

As is shown in table 5, if the average dominant hemlock on a plot is 22 inches in breast-height diameter the average dominant spruce on the same plot is about 23.52 inches in breast-height diameter and an average of the two heights involves an error of approximately 1½ feet.

On 28 of the 288 plots used, or on 9.72 percent of the total number of plots, the dominants averaged more than 20 inches in breast-height diameter. For these 28 plots the average breast-height diameter of dominants approximated 22 inches, and, therefore, the greatest error involved in averaging the two species is 1½ feet in height. Inasmuch as errors are inevitable in measuring diameters and heights and in curving total heights, this small discrepancy is not important.

## ROTATION AGE

Theoretically the age of culmination of mean annual increment, the year beyond which the total average increase in wood fiber per year becomes less, would be the rotation age (silvicultural rotation). Thus, according to the increment tables compiled in this study, the age at which second-growth stands in southeastern Alaska would be cut for pulpwood would be approximately 75 years. Many other factors enter into the choice of a rotation, however, and it may be desirable to postpone cutting for pulpwood until all the material is above a certain diameter (technical rotation). No rotation ages have as yet been determined for the region.

## YIELD TABLES

In the preparation of the yield tables the field and office methods outlined in the report of the committee on standardization of volume and yield tables of the Society of American Foresters (*6*), as modified by Bruce (*1*), have been followed. No particular difficulties necessitating a departure from these methods were encountered. In advance of the development of second-growth stands, no study of the application of these tables is possible.[2]

[2] A method of applying normal-yield tables to stands as found has been described by Meyer (*5*).

### YIELD TABLES FOR TOTAL STAND

Tables 4 to 8 and figures 3 to 6 give yield values for the entire stand per acre, including all trees having breast-height diameters as great as 0.6 inch. The figures given in table 8 are for volume of the entire stem including stump and tip, but not bark.

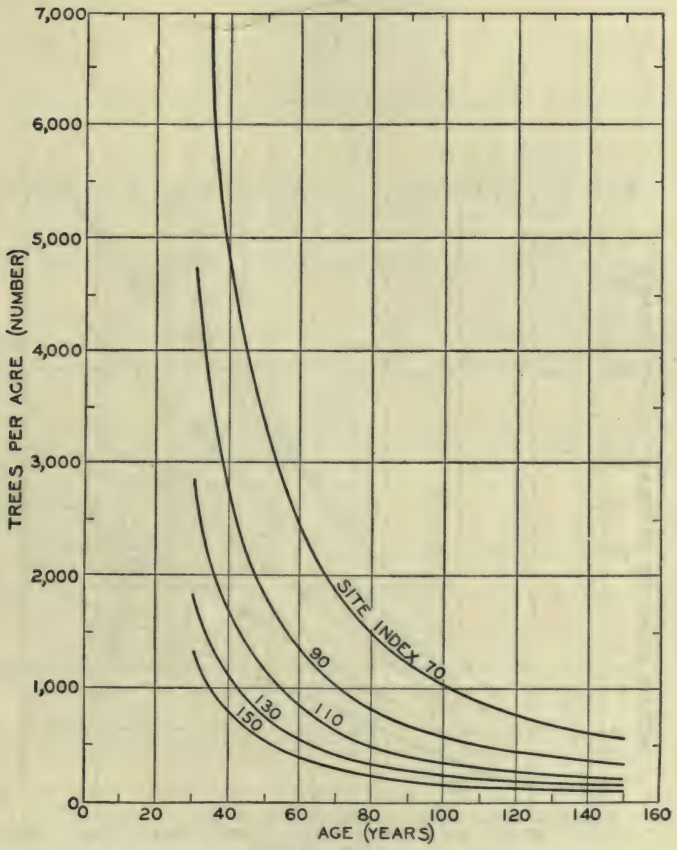


FIGURE 3.—Number of trees per acre, entire stand 0.6 inch and more in diameter at breast height.

As no volume tables existed for second-growth spruce or hemlock in Alaska, local tables were constructed for each tract on which sample plots were taken. From 15 to 40 or more trees were felled and measured on each area, care being taken to cover the entire range of diameters and crown classes. Such local tables should be more accurate than one regional volume table, and for this reason the volumes for each plot were read from the individual table constructed for that particular area.

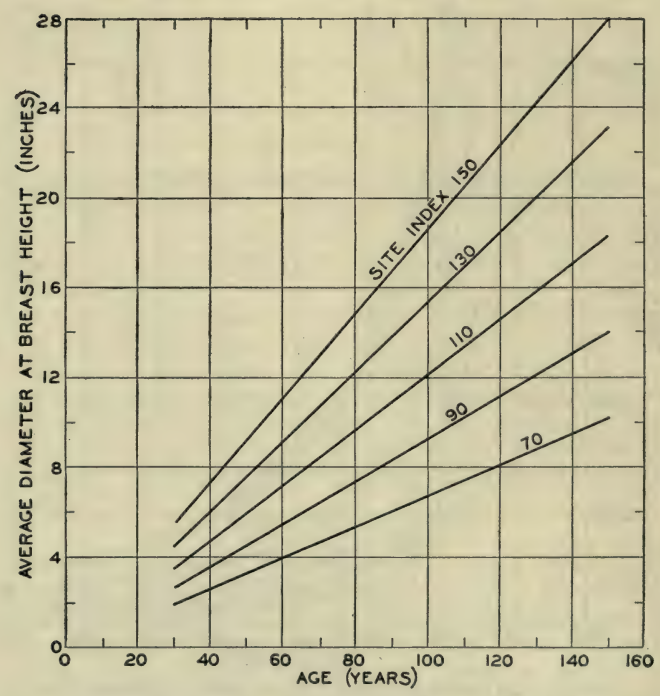


FIGURE 4.—Diameter of average tree at breast height, entire stand.

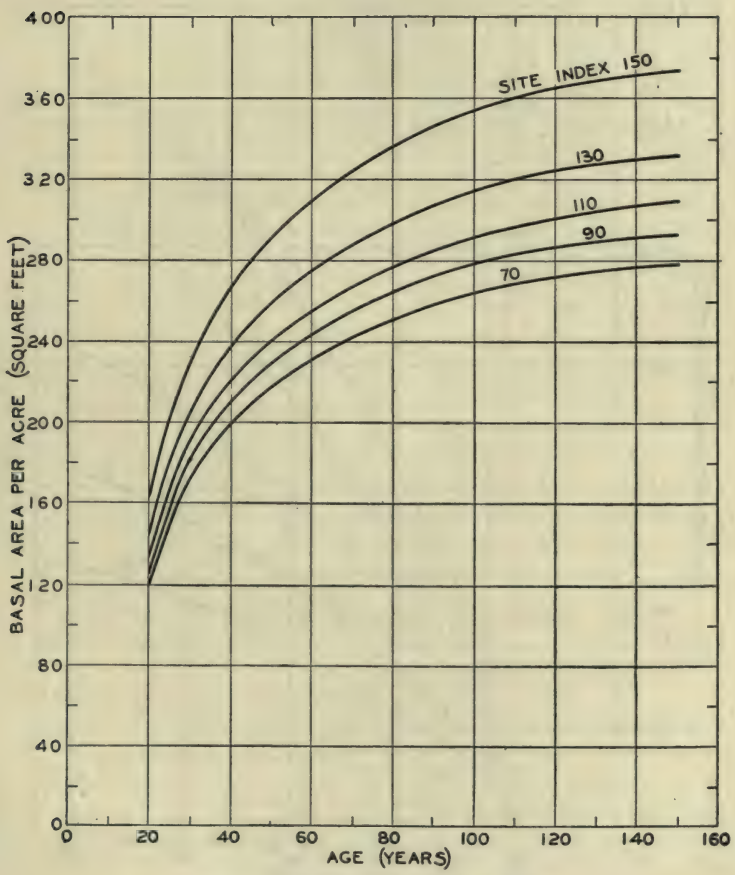


FIGURE 5.—Basal area per acre, entire stand.

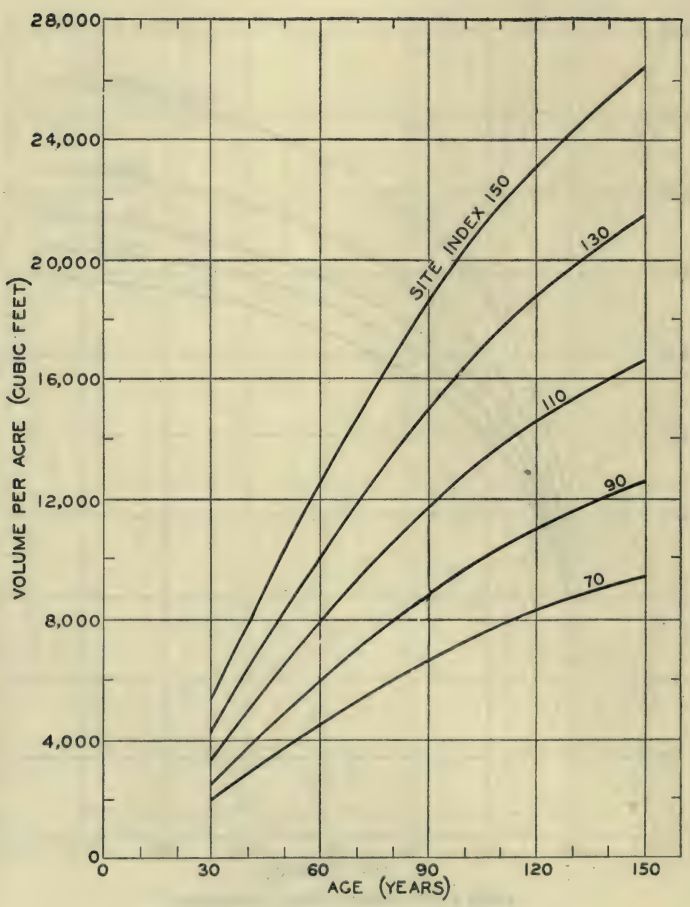


FIGURE 6.—Yield in cubic feet per acre, entire stand.

TABLE 4.—*Number of trees per acre, entire stand 0.6 inch and more in diameter at breast height*

| Age | Number of trees, by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 8,800 | 6,850 | 4,800 | 3,660 | 2,900 | 2,360 | 1,950 | 1,630 | 1,380 |
| 40 years | 4,900 | 3,660 | 2,770 | 2,140 | 1,670 | 1,350 | 1,100 | 910 | 770 |
| 50 years | 3,330 | 2,420 | 1,860 | 1,470 | 1,140 | 940 | 780 | 650 | 550 |
| 60 years | 2,440 | 1,760 | 1,360 | 1,050 | 830 | 660 | 550 | 460 | 390 |
| 70 years | 1,840 | 1,350 | 1,030 | 800 | 625 | 500 | 415 | 350 | 295 |
| 80 years | 1,470 | 1,090 | 815 | 625 | 495 | 400 | 335 | 275 | 225 |
| 90 years | 1,210 | 900 | 680 | 520 | 410 | 340 | 285 | 230 | 190 |
| 100 years | 1,040 | 770 | 580 | 450 | 350 | 290 | 240 | 200 | 160 |
| 110 years | 900 | 660 | 510 | 400 | 310 | 250 | 210 | 170 | 140 |
| 120 years | 800 | 570 | 450 | 350 | 270 | 220 | 180 | 150 | 120 |
| 130 years | 690 | 510 | 400 | 310 | 245 | 195 | 160 | 140 | 110 |
| 140 years | 620 | 460 | 350 | 275 | 220 | 175 | 150 | 125 | 105 |
| 150 years | 570 | 425 | 330 | 250 | 200 | 170 | 140 | 115 | 95 |

TABLE 5.—*Diameter of average tree at breast height, entire stand*

| Age | Diameter at breast height (in inches), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 1.9 | 2.3 | 2.6 | 3.1 | 3.5 | 4.1 | 4.5 | 4.9 | 5.4 |
| 40 years | 2.6 | 3.1 | 3.6 | 4.2 | 4.8 | 5.5 | 6.1 | 6.7 | 7.3 |
| 50 years | 3.3 | 3.9 | 4.5 | 5.3 | 6.0 | 6.8 | 7.6 | 8.4 | 9.2 |
| 60 years | 4.0 | 4.7 | 5.5 | 6.4 | 7.2 | 8.2 | 9.1 | 10.1 | 11.0 |
| 70 years | 4.7 | 5.5 | 6.4 | 7.4 | 8.4 | 9.6 | 10.7 | 11.8 | 12.9 |
| 80 years | 5.4 | 6.4 | 7.4 | 8.5 | 9.7 | 11.0 | 12.2 | 13.5 | 14.7 |
| 90 years | 6.1 | 7.2 | 8.3 | 9.6 | 10.9 | 12.4 | 13.8 | 15.3 | 16.6 |
| 100 years | 6.7 | 8.0 | 9.3 | 10.6 | 12.1 | 13.8 | 15.4 | 17.0 | 18.5 |
| 110 years | 7.4 | 8.8 | 10.2 | 11.7 | 13.4 | 15.1 | 16.9 | 18.7 | 20.4 |
| 120 years | 8.1 | 9.6 | 11.1 | 12.8 | 14.6 | 16.6 | 18.5 | 20.5 | 22.3 |
| 130 years | 8.8 | 10.4 | 12.1 | 13.9 | 15.9 | 18.0 | 20.0 | 22.2 | 24.2 |
| 140 years | 9.5 | 11.2 | 13.0 | 15.0 | 17.1 | 19.3 | 21.6 | 23.9 | 26.0 |
| 150 years | 10.2 | 12.1 | 14.0 | 16.0 | 18.3 | 20.8 | 23.1 | 25.6 | 28.0 |

TABLE 6.—*Total height of average tree (all crown classes)*

| Age | Total height (in feet), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 15 | 17 | 20 | 23 | 25 | 28 | 31 | 33 | 36 |
| 40 years | 22 | 26 | 30 | 34 | 38 | 43 | 47 | 51 | 55 |
| 50 years | 29 | 35 | 40 | 46 | 51 | 57 | 62 | 68 | 73 |
| 60 years | 36 | 43 | 50 | 56 | 63 | 70 | 77 | 83 | 90 |
| 70 years | 42 | 50 | 58 | 66 | 74 | 82 | 90 | 98 | 106 |
| 80 years | 48 | 57 | 66 | 75 | 84 | 93 | 102 | 111 | 119 |
| 90 years | 53 | 63 | 73 | 82 | 92 | 102 | 112 | 122 | 132 |
| 100 years | 57 | 67 | 78 | 88 | 98 | 110 | 120 | 131 | 141 |
| 110 years | 60 | 72 | 83 | 94 | 106 | 117 | 128 | 140 | 151 |
| 120 years | 64 | 76 | 88 | 100 | 112 | 124 | 136 | 148 | 159 |
| 130 years | 67 | 79 | 92 | 104 | 117 | 130 | 142 | 155 | 167 |
| 140 years | 69 | 82 | 95 | 108 | 121 | 134 | 147 | 160 | 173 |
| 150 years | 72 | 85 | 99 | 112 | 125 | 139 | 152 | 166 | 179 |

TABLE 7.—*Basal area* [1] *per acre, entire stand*

| Age | Basal area (in square feet), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 172 | 176 | 181 | 185 | 190 | 197 | 205 | 216 | 232 |
| 40 years | 199 | 203 | 210 | 214 | 220 | 228 | 237 | 250 | 267 |
| 50 years | 217 | 222 | 228 | 233 | 240 | 248 | 259 | 272 | 291 |
| 60 years | 230 | 237 | 243 | 248 | 255 | 264 | 275 | 289 | 310 |
| 70 years | 242 | 248 | 254 | 259 | 267 | 276 | 287 | 302 | 325 |
| 80 years | 250 | 257 | 264 | 270 | 277 | 286 | 298 | 314 | 337 |
| 90 years | 258 | 265 | 272 | 278 | 285 | 294 | 306 | 323 | 346 |
| 100 years | 263 | 270 | 277 | 284 | 291 | 301 | 313 | 331 | 354 |
| 110 years | 268 | 276 | 283 | 289 | 297 | 307 | 320 | 337 | 360 |
| 120 years | 272 | 280 | 287 | 293 | 301 | 311 | 324 | 342 | 365 |
| 130 years | 276 | 283 | 291 | 297 | 305 | 315 | 328 | 345 | 369 |
| 140 years | 277 | 285 | 292 | 299 | 307 | 317 | 331 | 348 | 372 |
| 150 years | 279 | 286 | 294 | 301 | 309 | 319 | 333 | 350 | 374 |

[1] Includes all trees having breast-height diameters as large as 0.6 inch.

TABLE 8.—*Yield* [1] *in cubic feet per acre, entire stand*

| Age | Yield per acre (in cubic feet), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 1,900 | 2,200 | 2,500 | 2,900 | 3,350 | 3,800 | 4,300 | 4,800 | 5,350 |
| 40 years | 2,775 | 3,220 | 3,680 | 4,260 | 4,905 | 5,570 | 6,310 | 7,040 | 7,800 |
| 50 years | 3,615 | 4,202 | 4,815 | 5,570 | 6,405 | 7,275 | 8,240 | 9,195 | 10,160 |
| 60 years | 4,420 | 5,142 | 5,900 | 6,820 | 7,837 | 8,905 | 10,085 | 11,255 | 12,420 |
| 70 years | 5,180 | 6,040 | 6,930 | 8,000 | 9,197 | 10,445 | 11,825 | 13,200 | 14,580 |
| 80 years | 5,890 | 6,880 | 7,890 | 9,105 | 10,477 | 11,885 | 13,450 | 15,020 | 16,615 |
| 90 years | 6,550 | 7,652 | 8,770 | 10,125 | 11,657 | 13,220 | 14,955 | 16,690 | 18,505 |
| 100 years | 7,160 | 8,362 | 9,572 | 11,055 | 12,737 | 14,445 | 16,340 | 18,220 | 20,225 |
| 110 years | 7,715 | 9,002 | 10,297 | 11,895 | 13,717 | 15,555 | 17,600 | 19,610 | 21,765 |
| 120 years | 8,215 | 9,577 | 10,919 | 12,650 | 14,597 | 16,555 | 18,730 | 20,860 | 23,135 |
| 130 years | 8,660 | 10,089 | 11,505 | 13,325 | 15,392 | 17,445 | 19,730 | 21,975 | 24,355 |
| 140 years | 9,050 | 10,539 | 12,035 | 13,925 | 16,109 | 18,235 | 20,610 | 22,955 | 25,435 |
| 150 years | 9,385 | 10,929 | 12,505 | 14,465 | 16,759 | 18,935 | 21,380 | 23,810 | 26,385 |

[1] Figures are for volume of entire stem, including stump and tip but not bark.

### YIELD TABLES FOR STAND 7 INCHES AND MORE IN DIAMETER

It has been estimated that pulp-timber cutting in southeastern Alaska would utilize only those trees 7 inches and more in diameter. On a rotation of more than 70 years, at the time of cutting few trees in the stand would be below this diameter except on the poorest sites. The number of trees 7 inches and more in breast-height diameter, shown by table 9 and figure 7, increases with age and growth until it includes all the trees in the stand. From then on, any mortality must decrease the total number of trees in this diameter class. On the best sites the time when all trees are 7 inches and more in diameter comes earlier in the life of the stand than on the poor sites. Yield data for this portion of the stand are given in tables 9–13 and figures 7–9.

Although the common practice in southeastern Alaska is to estimate all timber by the Scribner rule, that practice was not followed in compiling yield tables in the present study. The class of material to be cut in the second-growth forests will probably average less than 28 inches in diameter, and material of this size should be sold by cubic-foot contents. Applying the Scribner rule to such material would result in giving away many cubic feet of good pulpwood in the smaller trees. Table 12 gives yields in terms of merchantable cubic-foot

contents, showing the cubic volume per acre of all trees 7 inches in diameter and larger exclusive of bark and a 1-foot stump and to a

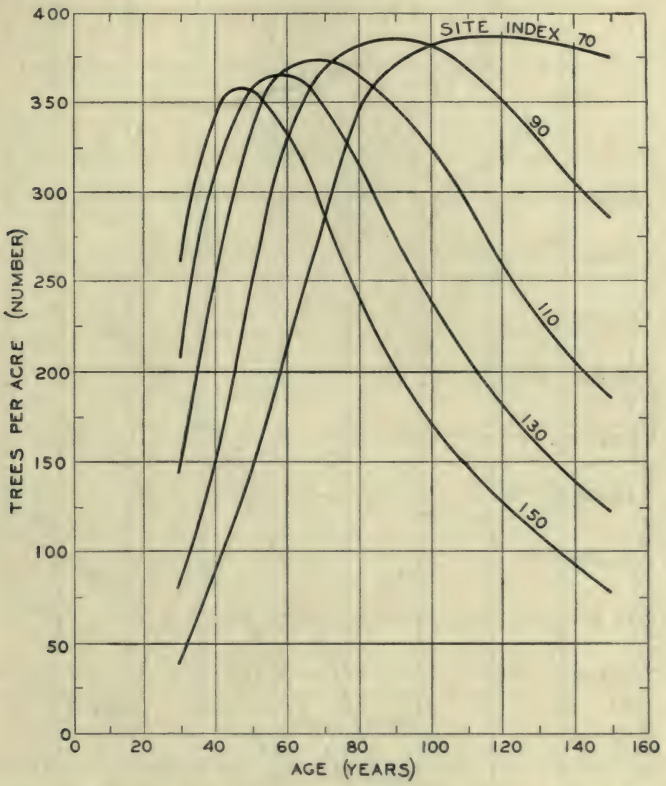


FIGURE 7.—Number of trees per acre 7 inches and more in diameter at breast height.

6-inch top diameter. Table 13 and figure 9 give yields for the stand 7 inches and more in diameter based on the International rule, which is more accurate than the Scribner rule for small logs.

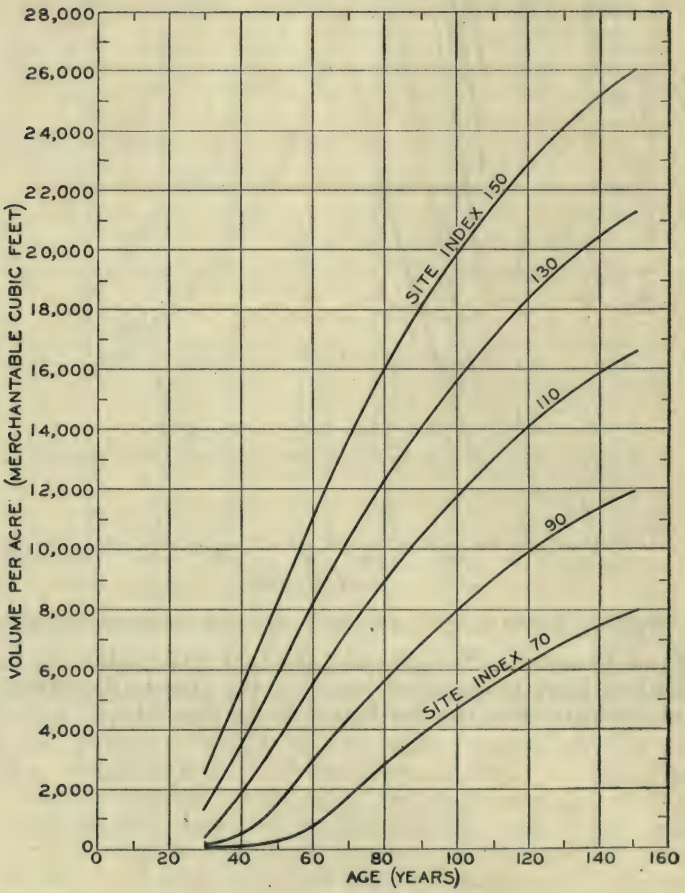


FIGURE 8.—Yield per acre in cubic feet, stand 7 inches and more in breast-height diameter, including stem above a 1-foot stump to a 6-inch top diameter inside bark.

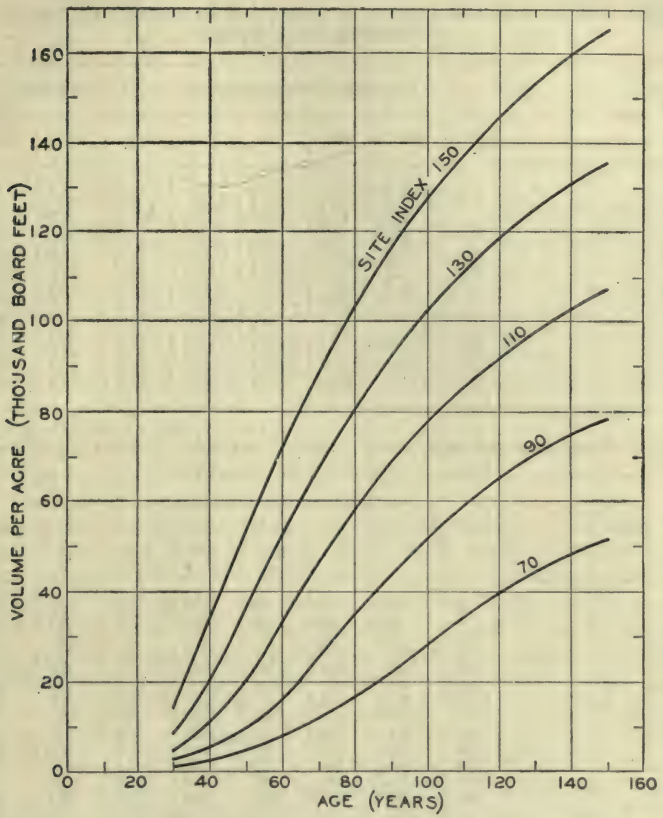


FIGURE 9.—Yield per acre in board feet by the International rule (¼-inch kerf), trees 7 inches and more in breast-height diameter.

TABLE 9.—*Number of trees per acre 7 inches and more in diameter at breast height* [1]

| Age | Number of trees, by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 39 | 56 | 78 | 106 | 145 | 181 | 209 | 233 | 262 |
| 40 years | 90 | 116 | 150 | 200 | 250 | 286 | 314 | 335 | 345 |
| 50 years | 146 | 188 | 245 | 310 | 335 | 349 | 359 | 362 | 355 |
| 60 years | 218 | 284 | 331 | 359 | 367 | 368 | 365 | 355 | 335 |
| 70 years | 286 | 349 | 367 | 374 | 373 | 363 | 347 | 325 | 289 |
| 80 years | 345 | 372 | 383 | 375 | 364 | 342 | 315 | 282 | 237 |
| 90 years | 371 | 382 | 387 | 369 | 347 | 314 | 276 | 237 | 202 |
| 100 years | 382 | 385 | 382 | 358 | 325 | 278 | 239 | 204 | 172 |
| 110 years | 386 | 379 | 369 | 342 | 295 | 241 | 208 | 177 | 149 |
| 120 years | 387 | 368 | 351 | 318 | 260 | 213 | 182 | 155 | 128 |
| 130 years | 386 | 355 | 329 | 286 | 229 | 189 | 158 | 135 | 110 |
| 140 years | 382 | 344 | 305 | 252 | 205 | 169 | 139 | 117 | 93 |
| 150 years | 377 | 335 | 285 | 226 | 185 | 150 | 122 | 100 | 78 |

[1] The 7-inch diameter class includes trees ranging from 6.6 inches to 7.5 inches in diameter at breast height.

TABLE 10.—*Diameter of average tree at breast height, stand 7 inches and more in diameter at breast height*

| Age | Diameter at breast height (in inches), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 7.5 | 7.6 | 7.7 | 7.9 | 8.1 | 8.3 | 8.5 | 8.7 | 9.0 |
| 40 years | 7.8 | 8.0 | 8.2 | 8.4 | 8.7 | 9.0 | 9.2 | 9.5 | 10.0 |
| 50 years | 8.0 | 8.3 | 8.6 | 8.9 | 9.3 | 9.7 | 10.0 | 10.5 | 11.2 |
| 60 years | 8.2 | 8.6 | 9.0 | 9.4 | 10.0 | 10.4 | 10.9 | 11.6 | 12.5 |
| 70 years | 8.4 | 9.0 | 9.4 | 10.0 | 10.6 | 11.3 | 12.0 | 12.8 | 13.9 |
| 80 years | 8.7 | 9.3 | 9.9 | 10.7 | 11.3 | 12.2 | 13.2 | 14.2 | 15.4 |
| 90 years | 9.0 | 9.7 | 10.4 | 11.3 | 12.1 | 13.2 | 14.4 | 15.7 | 17.0 |
| 100 years | 9.3 | 10.1 | 10.9 | 12.0 | 12.9 | 14.2 | 15.6 | 17.2 | 18.7 |
| 110 years | 9.7 | 10.6 | 11.5 | 12.7 | 13.8 | 15.4 | 17.0 | 18.7 | 20.5 |
| 120 years | 10.1 | 11.1 | 12.1 | 13.5 | 14.8 | 16.5 | 18.4 | 20.3 | 22.4 |
| 130 years | 10.6 | 11.7 | 12.8 | 14.4 | 15.9 | 17.8 | 19.9 | 22.0 | 24.3 |
| 140 years | 11.1 | 12.3 | 13.6 | 15.3 | 17.1 | 19.3 | 21.5 | 23.8 | 26.2 |
| 150 years | 11.7 | 13.0 | 14.6 | 16.5 | 18.6 | 20.9 | 23.2 | 25.7 | 28.2 |

TABLE 11.—*Basal area per acre, stand 7 inches and more in diameter at breast height*

| Age | Basal area per acre (in square feet), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 13 | 20 | 26 | 38 | 50 | 67 | 86 | 103 | 130 |
| 40 years | 30 | 42 | 60 | 76 | 100 | 126 | 151 | 183 | 211 |
| 50 years | 51 | 71 | 95 | 125 | 153 | 181 | 207 | 234 | 261 |
| 60 years | 77 | 107 | 136 | 171 | 198 | 223 | 247 | 268 | 294 |
| 70 years | 108 | 147 | 179 | 209 | 233 | 252 | 271 | 292 | 317 |
| 80 years | 140 | 181 | 211 | 236 | 255 | 272 | 290 | 309 | 333 |
| 90 years | 171 | 208 | 234 | 255 | 271 | 286 | 302 | 321 | 344 |
| 100 years | 196 | 228 | 250 | 269 | 283 | 297 | 311 | 329 | 353 |
| 110 years | 215 | 244 | 264 | 279 | 292 | 304 | 318 | 336 | 359 |
| 120 years | 230 | 256 | 274 | 287 | 299 | 310 | 323 | 341 | 364 |
| 130 years | 243 | 266 | 281 | 293 | 303 | 314 | 327 | 345 | 368 |
| 140 years | 253 | 272 | 287 | 297 | 306 | 317 | 330 | 348 | 371 |
| 150 years | 260 | 278 | 291 | 299 | 308 | 319 | 333 | 350 | 374 |

TABLE 12.—*Yield per acre in merchantable cubic feet,*[1] *stand 7 inches and more in diameter at breast height*

| Age | Yield per acre (in merchantable cubic feet), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 57 | 99 | 145 | 232 | 352 | 570 | 1,290 | 1,920 | 2,595 |
| 40 years | 157 | 279 | 485 | 942 | 1,772 | 2,560 | 3,490 | 4,380 | 5,395 |
| 50 years | 377 | 679 | 1,485 | 2,492 | 3,622 | 4,610 | 5,750 | 6,890 | 8,255 |
| 60 years | 807 | 1,769 | 2,905 | 4,142 | 5,482 | 6,670 | 8,010 | 9,410 | 11,095 |
| 70 years | 1,770 | 3,069 | 4,335 | 5,712 | 7,262 | 8,670 | 10,210 | 11,850 | 13,745 |
| 80 years | 2,857 | 4,289 | 5,655 | 7,182 | 8,922 | 10,530 | 12,290 | 14,040 | 16,075 |
| 90 years | 3,827 | 5,439 | 6,865 | 8,542 | 10,452 | 12,220 | 14,130 | 15,970 | 18,125 |
| 100 years | 4,697 | 6,439 | 7,965 | 9,772 | 11,822 | 13,720 | 15,750 | 17,670 | 19,925 |
| 110 years | 5,477 | 7,339 | 8,965 | 10,882 | 13,042 | 15,040 | 17,180 | 19,170 | 21,505 |
| 120 years | 6,177 | 8,139 | 9,865 | 11,872 | 14,122 | 16,200 | 18,430 | 20,480 | 22,885 |
| 130 years | 6,817 | 8,859 | 10,665 | 12,752 | 15,072 | 17,220 | 19,520 | 21,630 | 24,085 |
| 140 years | 7,397 | 9,509 | 11,375 | 13,522 | 15,892 | 18,100 | 20,480 | 22,630 | 25,145 |
| 150 years | 7,917 | 10,089 | 11,995 | 14,182 | 16,602 | 18,860 | 21,320 | 23,510 | 26,075 |

[1] Utilization to a 6-inch top inside bark, exclusive of a 1-foot stump.

TABLE 13.—*Yield per acre in board feet, International rule (⅛-inch kerf),*[1] *stand 7 inches and more in diameter at breast height*

| Age | Yield per acre (in board feet, International rule), by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 950 | 1,540 | 2,200 | 3,335 | 4,656 | 6,422 | 8,600 | 11,520 | 14,498 |
| 40 years | 2,420 | 3,590 | 5,200 | 7,905 | 10,876 | 15,722 | 20,500 | 28,120 | 34,498 |
| 50 years | 4,590 | 6,710 | 9,700 | 14,525 | 19,996 | 28,472 | 36,500 | 47,020 | 54,398 |
| 60 years | 7,550 | 11,110 | 16,050 | 24,325 | 32,896 | 43,732 | 53,050 | 64,670 | 73,028 |
| 70 years | 11,440 | 17,160 | 25,150 | 35,325 | 46,076 | 58,232 | 68,220 | 80,390 | 89,708 |
| 80 years | 16,440 | 25,220 | 35,100 | 45,975 | 57,796 | 70,832 | 81,400 | 94,060 | 104,128 |
| 90 years | 22,570 | 33,280 | 44,130 | 55,695 | 68,146 | 81,832 | 92,900 | 105,960 | 116,728 |
| 100 years | 29,080 | 40,560 | 52,160 | 64,315 | 77,246 | 91,382 | 102,850 | 116,360 | 127,818 |
| 110 years | 34,910 | 47,060 | 59,230 | 71,915 | 85,206 | 99,682 | 111,470 | 125,420 | 137,518 |
| 120 years | 40,070 | 52,780 | 65,380 | 78,465 | 92,026 | 106,802 | 118,900 | 133,300 | 146,008 |
| 130 years | 44,520 | 57,750 | 70,680 | 84,085 | 97,886 | 112,902 | 125,300 | 140,100 | 153,408 |
| 140 years | 48,290 | 61,950 | 75,200 | 88,905 | 102,896 | 118,112 | 130,800 | 146,000 | 159,898 |
| 150 years | 51,360 | 65,450 | 79,000 | 93,025 | 107,196 | 122,612 | 135,600 | 151,180 | 165,598 |

[1] To a 5-inch top inside bark, exclusive of a 1-foot stump.

### APPLICATION OF YIELD TABLES

By referring to tables 4 to 8 the normal yield at any age may be determined for any site index. The table figures, since they are based on fully stocked stands, are too high for the usual second-growth forest. In yield estimates covering large areas a general reduction factor must be applied. For a small area an individual reduction factor is determined by comparing the basal area per acre of the stand being examined with that of the normal stand as shown in table 7. If the basal area of the stand is found to be 90 percent of the tabular value for stands of its age and site index, in predicting future yields the values given in the tables must be reduced by 10 percent. The accuracy of this procedure may be affected somewhat by a tendency of understocked stands to approach normal stocking. Investigations to determine whether such a tendency exists are being carried on by the Forest Service.

In order to determine the approximate average stocking of second-growth areas as compared with fully or normally stocked stands, strip surveys were run through many of the young forests in which the fully stocked plots were measured. Density on large areas, in terms of basal area, was found to range from 60.8 percent to 104.9 percent of normal and to average 88.6 percent of normal. The average deviation of individual areas from this figure was 11 percent. Understocking seemed to be due to small openings in the stand rather than to wide spacing.

In applying the tables over large tracts of second growth it is necessary to make a detailed cruise to determine the various sites and reduction factors. Instructions for both field and office work of this nature are given by Meyer (*4*). It should be borne in mind that the tables do not take into account any loss through defect or breakage.

The tables presented here are of little use, as applied by any method yet devised, in predicting future yields pending removal of the all-aged virgin forest which covers the greater portion of the region and actual restocking. If a given stand has not progressed beyond even-agedness the tables are applicable, but if the main stand is uneven-aged they are not. In the existing forests little or no gain in height is

shown at ages beyond approximately 300 years. It would seem logical, therefore, to assume that if all the dominants in a given all-aged mixed stand are 300 years old or older the site index can be determined from the curves given here. As a matter of fact, the index cannot be reliably determined in this way; the stand may not contain a single tree that was originally present in the even-aged stand, and since the western hemlock's total height at maturity is less than that of Sitka spruce the gradual increase in hemlock content in such stands has caused an actual decrease in the average heights of the dominants.

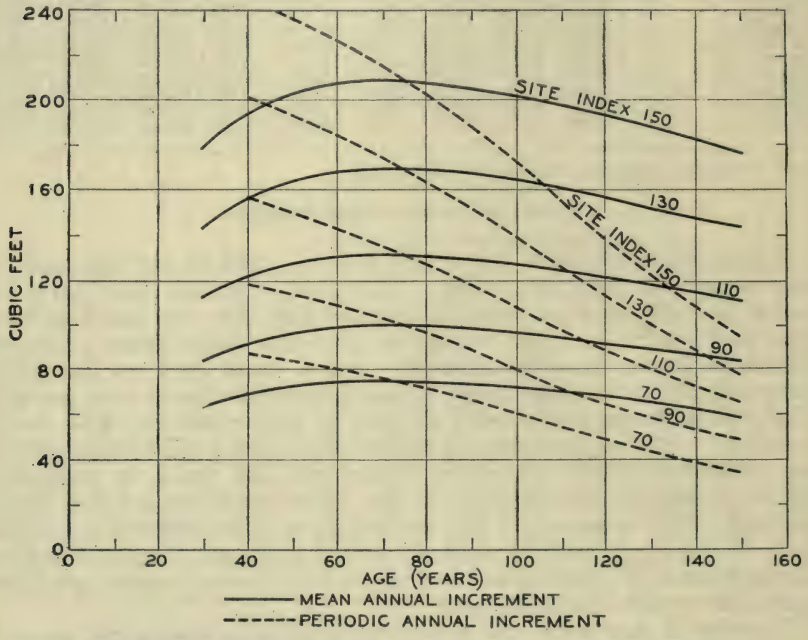


FIGURE 10.—Mean and periodic annual increment per acre in cubic feet, entire stand.

Investigations by the writer show that old-growth stands when cut invariably are succeeded by even-aged forests having a far higher site index.

## INCREMENT TABLES

Tables 14, 15, and 16 and figures 10, 11, and 12 indicate the mean and periodic (10-year) annual increment for the entire stand in cubic feet, and for the stand 7 inches and more in diameter at breast height in merchantable cubic feet and in board feet by the International rule.

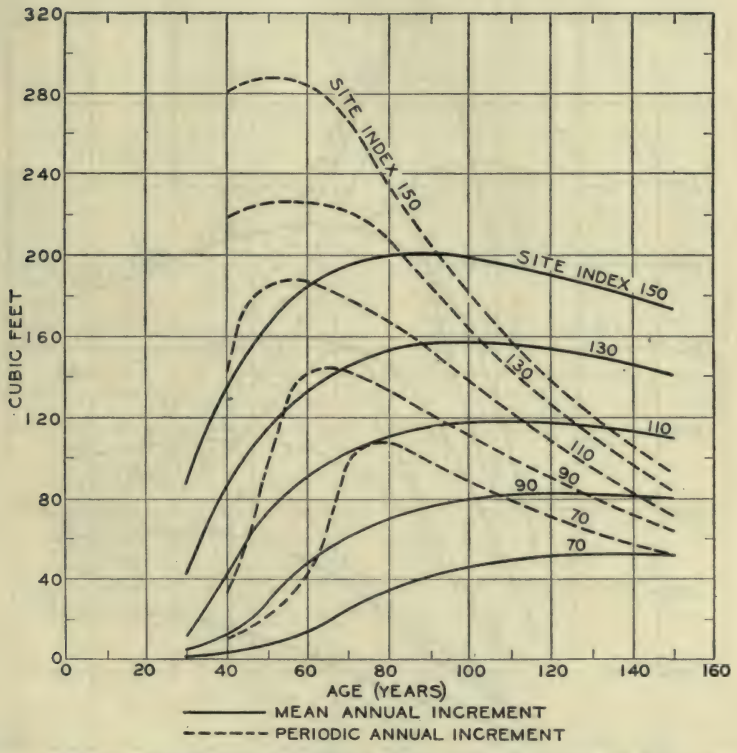


FIGURE 11.—Mean and periodic annual increment per acre in merchantable cubic feet, stand 7 inches and more in breast-height diameter.

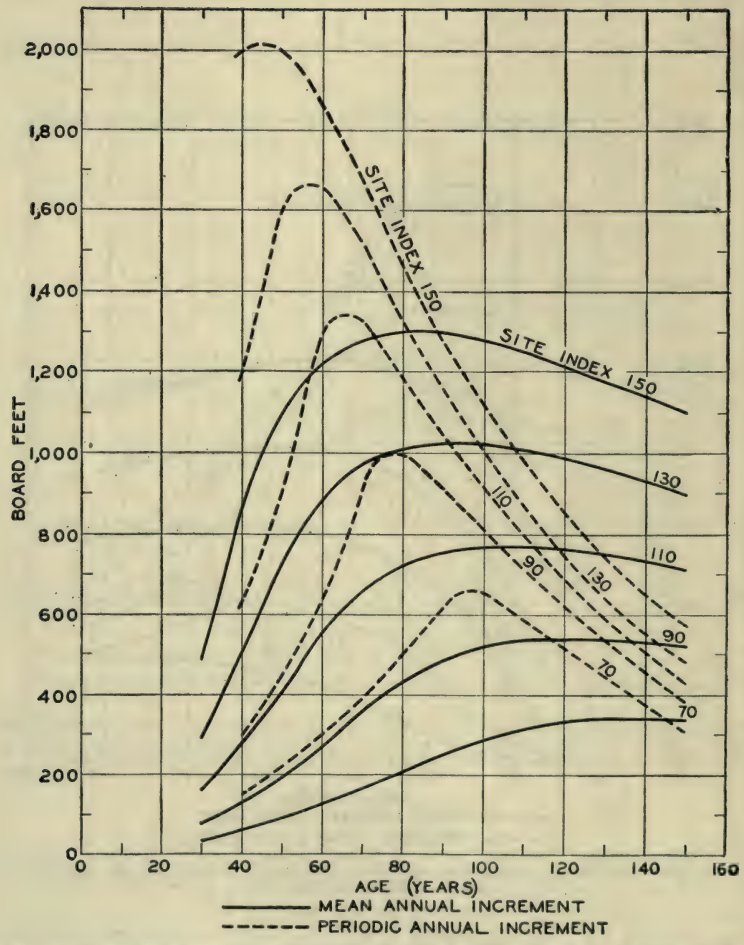


FIGURE 12.—Mean and periodic annual increment per acre in board feet by the International (⅛-inch kerf) rule, stand 7 inches and more in breast-height diameter.

TABLE 14.—*Increment* [1] *per acre in cubic feet, entire stand*

MEAN ANNUAL INCREMENT

| Age | Cubic feet per acre, by site index— | | | | |
|---|---|---|---|---|---|
| | 70 | 90 | 110 | 130 | 150 |
| 30 years | 63 | 84 | 112 | 143 | 178 |
| 40 years | 70 | 91 | 122 | 158 | 196 |
| 50 years | 73 | 96 | 128 | 164 | 204 |
| 60 years | 74 | 98 | 130 | 167 | 208 |
| 70 years | 75 | 99 | 131 | 168 | 209 |
| 80 years | 74 | 99 | 130 | 168 | 208 |
| 90 years | 73 | 98 | 129 | 167 | 206 |
| 100 years | 72 | 96 | 127 | 164 | 202 |
| 110 years | 71 | 94 | 124 | 161 | 198 |
| 120 years | 69 | 92 | 122 | 157 | 193 |
| 130 years | 67 | 90 | 118 | 152 | 188 |
| 140 years | 60 | 87 | 115 | 148 | 182 |
| 150 years | 58 | 84 | 111 | 143 | 176 |

PERIODIC ANNUAL INCREMENT

| AGE CLASS | | | | | |
|---|---|---|---|---|---|
| 30 to 40 years | 87 | 118 | 156 | 201 | 245 |
| 40 to 50 years | 84 | 114 | 150 | 193 | 236 |
| 50 to 60 years | 80 | 108 | 143 | 184 | 226 |
| 60 to 70 years | 76 | 103 | 136 | 174 | 216 |
| 70 to 80 years | 71 | 96 | 128 | 162 | 204 |
| 80 to 90 years | 66 | 88 | 118 | 150 | 189 |
| 90 to 100 years | 61 | 80 | 108 | 138 | 172 |
| 100 to 110 years | 56 | 72 | 98 | 126 | 154 |
| 110 to 120 years | 50 | 64 | 88 | 113 | 137 |
| 120 to 130 years | 44 | 58 | 80 | 100 | 122 |
| 130 to 140 years | 39 | 53 | 72 | 88 | 108 |
| 140 to 150 years | 34 | 47 | 65 | 77 | 95 |

[1] Utilization to a 6-inch top.

TABLE 15.—*Increment* [1] *per acre in cubic feet, stand 7 inches and more in diameter at breast height*

MEAN ANNUAL INCREMENT

| Age | Merchantable cubic feet per acre, by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 2 | 3 | 5 | 8 | 12 | 19 | 43 | 64 | 86 |
| 40 years | 4 | 7 | 12 | 24 | 44 | 64 | 87 | 110 | 135 |
| 50 years | 8 | 14 | 30 | 50 | 72 | 92 | 115 | 138 | 165 |
| 60 years | 13 | 30 | 48 | 69 | 92 | 111 | 134 | 157 | 185 |
| 70 years | 25 | 44 | 62 | 82 | 104 | 124 | 146 | 169 | 196 |
| 80 years | 36 | 54 | 71 | 90 | 112 | 132 | 154 | 176 | 201 |
| 90 years | 42 | 60 | 76 | 95 | 116 | 136 | 157 | 177 | 202 |
| 100 years | 47 | 64 | 80 | 98 | 118 | 137 | 158 | 177 | 199 |
| 110 years | 50 | 67 | 82 | 99 | 118 | 137 | 156 | 174 | 195 |
| 120 years | 52 | 68 | 82 | 99 | 118 | 135 | 154 | 171 | 190 |
| 130 years | 52 | 68 | 82 | 98 | 116 | 132 | 150 | 166 | 185 |
| 140 years | 53 | 68 | 81 | 97 | 113 | 129 | 146 | 162 | 180 |
| 150 years | 53 | 67 | 80 | 94 | 111 | 126 | 142 | 157 | 174 |

PERIODIC ANNUAL INCREMENT

| AGE CLASS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 30 to 40 years | 10 | 18 | 34 | 71 | 142 | 199 | 220 | 246 | 280 |
| 40 to 50 years | 22 | 40 | 100 | 155 | 185 | 205 | 226 | 251 | 286 |
| 50 to 60 years | 43 | 109 | 142 | 165 | 186 | 206 | 226 | 252 | 284 |
| 60 to 70 years | 97 | 130 | 143 | 157 | 178 | 200 | 220 | 244 | 265 |
| 70 to 80 years | 108 | 122 | 132 | 147 | 166 | 186 | 208 | 219 | 233 |
| 80 to 90 years | 97 | 115 | 121 | 136 | 153 | 169 | 184 | 193 | 205 |
| 90 to 100 years | 87 | 100 | 110 | 123 | 137 | 150 | 162 | 170 | 180 |
| 100 to 110 years | 78 | 90 | 100 | 111 | 122 | 132 | 143 | 150 | 158 |
| 110 to 120 years | 70 | 80 | 90 | 99 | 108 | 116 | 125 | 131 | 138 |
| 120 to 130 years | 64 | 72 | 80 | 88 | 95 | 102 | 109 | 115 | 120 |
| 130 to 140 years | 58 | 65 | 71 | 77 | 82 | 88 | 96 | 100 | 106 |
| 140 to 150 years | 52 | 58 | 62 | 66 | 71 | 76 | 84 | 88 | 93 |

[1] Utilization to a 6-inch top.

TABLE 16.—*Increment*[1] *per acre in board feet by International rule (⅛-inch kerf), stand 7 inches and more in diameter at breast height*

MEAN ANNUAL INCREMENT

| Age | Board feet per acre, by site index— | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 30 years | 31.6 | 51.4 | 73.3 | 111 | 155 | 214 | 286 | 385 | 483 |
| 40 years | 60.3 | 90.0 | 130.0 | 197 | 271 | 393 | 512 | 703 | 864 |
| 50 years | 91.7 | 134.0 | 194.0 | 290 | 400 | 570 | 730 | 942 | 1,083 |
| 60 years | 126.0 | 185.0 | 267.0 | 406 | 549 | 729 | 884 | 1,078 | 1,220 |
| 70 years | 164.0 | 245.0 | 359.0 | 505 | 660 | 831 | 973 | 1,148 | 1,280 |
| 80 years | 206.0 | 315.0 | 439.0 | 574 | 722 | 886 | 1,012 | 1,175 | 1,299 |
| 90 years | 250.0 | 370.0 | 490.0 | 619 | 759 | 910 | 1,030 | 1,175 | 1,295 |
| 100 years | 291.0 | 406.0 | 522.0 | 643 | 772 | 913 | 1,028 | 1,163 | 1,278 |
| 110 years | 317.0 | 428.0 | 537.0 | 653 | 773 | 903 | 1,014 | 1,140 | 1,250 |
| 120 years | 334.0 | 439.0 | 544.0 | 652 | 766 | 890 | 990 | 1,110 | 1,215 |
| 130 years | 342.0 | 444.0 | 542.0 | 646 | 751 | 869 | 966 | 1,076 | 1,178 |
| 140 years | 344.0 | 442.0 | 536.0 | 635 | 733 | 845 | 934 | 1,041 | 1,140 |
| 150 years | 342.0 | 436.0 | 526.0 | 620 | 715 | 819 | 902 | 1,008 | 1,103 |

PERIODIC ANNUAL INCREMENT

| AGE CLASS | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 30 to 40 years | 147 | 205 | 300 | 457 | 622 | 930 | 1,190 | 1,660 | 2,000 |
| 40 to 50 years | 217 | 312 | 450 | 662 | 912 | 1,275 | 1,600 | 1,890 | 1,990 |
| 50 to 60 years | 296 | 440 | 635 | 980 | 1,290 | 1,526 | 1,655 | 1,765 | 1,863 |
| 60 to 70 years | 389 | 605 | 910 | 1,100 | 1,318 | 1,450 | 1,517 | 1,572 | 1,668 |
| 70 to 80 years | 500 | 806 | 995 | 1,065 | 1,172 | 1,260 | 1,318 | 1,367 | 1,442 |
| 80 to 90 years | 613 | 806 | 903 | 972 | 1,035 | 1,100 | 1,150 | 1,190 | 1,260 |
| 90 to 100 years | 651 | 728 | 803 | 862 | 910 | 955 | 995 | 1,040 | 1,109 |
| 100 to 110 years | 583 | 650 | 707 | 760 | 796 | 830 | 862 | 906 | 970 |
| 110 to 120 years | 516 | 572 | 615 | 655 | 682 | 712 | 743 | 788 | 849 |
| 120 to 130 years | 445 | 497 | 530 | 562 | 586 | 610 | 640 | 680 | 740 |
| 130 to 140 years | 377 | 420 | 452 | 482 | 501 | 521 | 550 | 590 | 649 |
| 140 to 150 years | 307 | 350 | 380 | 412 | 430 | 450 | 480 | 518 | 570 |

[1] Utilization to a 6-inch top.

## STAND TABLES

The stand tables developed in this study (table 18) are for alternate decades from 30 to 150 years and alternate site indices from 70 to 150. They indicate what number of trees per acre will be found in any diameter class for these ages and sites.

A stand table for any given age or site may be constructed by use of the stand-table alinement chart shown in figure 13, which was constructed according to methods described by Bruce and Reineke (*2*). If, for example, it is desired to construct a stand table for age 100 years and site index 140 we refer to tables 4 and 5 and find the total number of trees to be 200 per acre and the average diameter 17 inches. A straight edge is laid across the three scales of the alinement chart, passing through the upper diameter limit desired on the left and the average diameter (17 inches) in the center. The number of trees below this diameter limit in percentage of the total number is read from the right-hand scale. The computation in table 17 illustrates this method.

TABLE 17.—*Stand table for age 50 years, site index 70*

| Breast-height diameter class (inches) | Upper diameter limit | Trees below upper limit | | Trees in diameter class | Breast-height diameter class (inches) | Upper diameter limit | Trees below upper limit | | Trees in diameter class |
|---|---|---|---|---|---|---|---|---|---|
| | *Inches* | *Percent* | *Number* | *Number* | | *Inches* | *Percent* | *Number* | *Number* |
| Less than 2 | 1.5 | 25.00 | 832 | 832 | 4 | 4.5 | 88.25 | 2,930 | 455 |
| 2 | 2.5 | 51.00 | 1,690 | 858 | 5 | 5.5 | 95.90 | 3,180 | 250 |
| 3 | 3.5 | 74.50 | 2,475 | 785 | 6 | 6.5 | 100.00 | 3,330 | 150 |

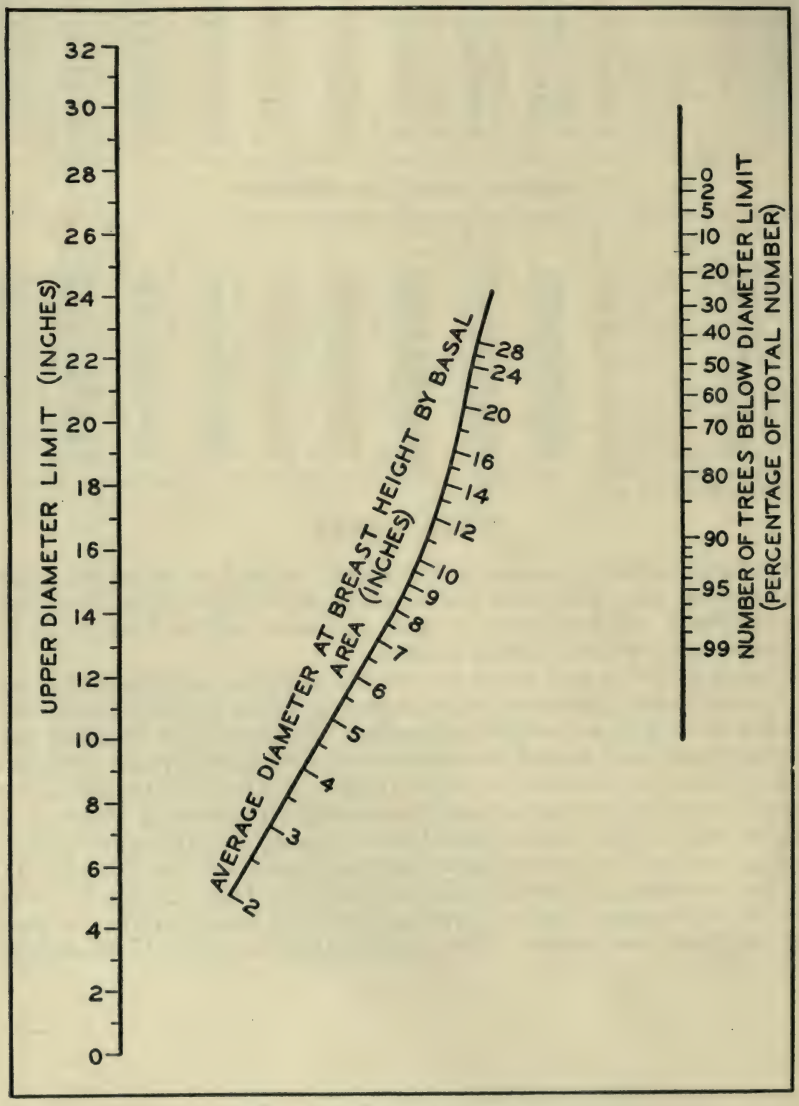


FIGURE 13.—Stand-table alinement chart.

TABLE 18.—*Stand tables for even-aged western hemlock-Sitka spruce in southeastern Alaska*

SITE INDEX 70

| Diameter class (inches) | Number of trees per acre, by age class— | | | | | | |
|---|---|---|---|---|---|---|---|
| | 30 years | 50 years | 70 years | 90 years | 110 years | 130 years | 150 years |
| Less than 2 | 6,500 | 832 | 217 | 85 | 41 | 10 | |
| 2 | 1,890 | 858 | 279 | 121 | 64 | 30 | 11 |
| 3 | 410 | 785 | 334 | 154 | 84 | 44 | 27 |
| 4 | | 455 | 331 | 175 | 103 | 54 | 33 |
| 5 | | 250 | 265 | 170 | 104 | 66 | 40 |
| 6 | | 150 | 175 | 157 | 109 | 70 | 51 |
| 7 | | | 120 | 118 | 101 | 74 | 49 |
| 8 | | | 78 | 80 | 81 | 67 | 57 |
| 9 | | | 42 | 60 | 63 | 65 | 52 |
| 10 | | | | 41 | 47 | 49 | 48 |
| 11 | | | | 38 | 35 | 42 | 42 |
| 12 | | | | 11 | 28 | 29 | 36 |
| 13 | | | | | 23 | 28 | 29 |
| 14 | | | | | 17 | 19 | 23 |
| 15 | | | | | | 17 | 20 |
| 16 | | | | | | 13 | 15 |
| 17 | | | | | | 13 | 12 |
| 18 | | | | | | | 11 |
| 19 | | | | | | | 11<br>3 |

SITE INDEX 90

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Less than 2 | 1,970 | 246 | 62 | 14 | | | |
| 2 | 1,530 | 294 | 93 | 40 | 13 | | |
| 3 | 860 | 390 | 133 | 48 | 23 | 1 | |
| 4 | 380 | 320 | 134 | 61 | 30 | 16 | |
| 5 | 60 | 260 | 139 | 75 | 38 | 19 | 9 |
| 6 | | 160 | 134 | 75 | 44 | 24 | 11 |
| 7 | | 100 | 108 | 75 | 50 | 28 | 15 |
| 8 | | 73 | 72 | 68 | 44 | 30 | 21 |
| 9 | | 17 | 59 | 54 | 46 | 36 | 22 |
| 10 | | | 38 | 47 | 43 | 34 | 24 |
| 11 | | | 33 | 33 | 38 | 32 | 25 |
| 12 | | | 25 | 27 | 33 | 32 | 26 |
| 13 | | | | 22 | 26 | 30 | 27 |
| 14 | | | | 16 | 19 | 23 | 24 |
| 15 | | | | 15 | 16 | 19 | 22 |
| 16 | | | | 10 | 14 | 18 | 21 |
| 17 | | | | | 10 | 14 | 16 |
| 18 | | | | | 10 | 10 | 14 |
| 19 | | | | | 10 | 9 | 10 |
| 20 | | | | | | 9 | 10 |
| 21 | | | | | | 7 | 8 |
| 22 | | | | | | 6 | 7 |
| 23 | | | | | | 3 | 6 |
| 24 | | | | | | | 6 |
| 25 | | | | | | | 4<br>2 |

TABLE 18.—*Stand tables for even-aged western hemlock-Sitka spruce in southeastern Alaska*—Continued

SITE INDEX 110

| Diameter class (inches) | Number of trees per acre, by age class— | | | | | | |
|---|---|---|---|---|---|---|---|
| | 30 years | 50 years | 70 years | 90 years | 110 years | 130 years | 150 years |
| Less than 2 | 650 | 91 | 12 | | | | |
| 2 | 710 | 111 | 32 | | | | |
| 3 | 682 | 157 | 48 | 17 | | | |
| 4 | 420 | 166 | 49 | 20 | 3 | | |
| 5 | 258 | 170 | 67 | 25 | 11 | | |
| 6 | 160 | 141 | 64 | 30 | 14 | 3 | |
| 7 | 20 | 110 | 64 | 33 | 18 | 9 | |
| 8 | | 74 | 64 | 39 | 18 | 10 | 4 |
| 9 | | 50 | 56 | 36 | 23 | 12 | 6 |
| 10 | | 40 | 44 | 36 | 26 | 15 | 8 |
| 11 | | 30 | 31 | 32 | 24 | 15 | 10 |
| 12 | | | 29 | 29 | 24 | 17 | 11 |
| 13 | | | 20 | 27 | 24 | 20 | 11 |
| 14 | | | 16 | 19 | 24 | 19 | 14 |
| 15 | | | 14 | 15 | 20 | 17 | 14 |
| 16 | | | 14 | 14 | 16 | 17 | 14 |
| 17 | | | 1 | 10 | 14 | 16 | 14 |
| 18 | | | | 10 | 10 | 13 | 14 |
| 19 | | | | 7 | 11 | 12 | 12 |
| 20 | | | | 7 | 8 | 10 | 12 |
| 21 | | | | 4 | 6 | 7 | 10 |
| 22 | | | | | 6 | 7 | 8 |
| 23 | | | | | 5 | 7 | 7 |
| 24 | | | | | 4 | 4 | 6 |
| 25 | | | | | 2 | 4 | 6 |
| 26 | | | | | | 4 | 4 |
| 27 | | | | | | 4 | 4 |
| 28 | | | | | | 3 | 3 |
| 29 | | | | | | | 3 |
| 30 | | | | | | | 3 |
| 31 | | | | | | | 2 |

SITE INDEX 130

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Less than 2 | 254 | 37 | | | | | |
| 2 | 321 | 51 | | | | | |
| 3 | 380 | 76 | 20 | | | | |
| 4 | 355 | 86 | 21 | | | | |
| 5 | 270 | 97 | 25 | 10 | | | |
| 6 | 170 | 103 | 32 | 13 | | | |
| 7 | 110 | 79 | 39 | 15 | 4 | | |
| 8 | 70 | 66 | 37 | 16 | 8 | | |
| 9 | 20 | 55 | 37 | 20 | 9 | 3 | |
| 10 | | 40 | 36 | 22 | 10 | 5 | |
| 11 | | 31 | 33 | 22 | 11 | 6 | 3 |
| 12 | | 24 | 29 | 25 | 15 | 8 | 4 |
| 13 | | 20 | 24 | 20 | 15 | 8 | 5 |
| 14 | | 15 | 19 | 20 | 15 | 9 | 6 |
| 15 | | | 16 | 17 | 16 | 11 | 7 |
| 16 | | | 12 | 16 | 15 | 10 | 7 |
| 17 | | | 10 | 13 | 13 | 12 | 9 |
| 18 | | | 8 | 11 | 13 | 10 | 9 |
| 19 | | | 8 | 10 | 11 | 11 | 8 |
| 20 | | | 8 | 8 | 11 | 10 | 10 |
| 21 | | | 1 | 6 | 8 | 9 | 8 |
| 22 | | | | 6 | 7 | 8 | 8 |
| 23 | | | | 5 | 7 | 7 | 8 |
| 24 | | | | 5 | 5 | 6 | 8 |
| 25 | | | | 3 | 4 | 5 | 6 |
| 26 | | | | | 4 | 4 | 6 |
| 27 | | | | | 3 | 4 | 5 |
| 28 | | | | | 2 | 3 | 4 |
| 29 | | | | | 2 | 3 | 4 |
| 30 | | | | | 2 | 2 | 2 |
| 31 | | | | | | 3 | 2 |
| 32 | | | | | | 1 | 3 |
| 33 | | | | | | 2 | 2 |
| 34 | | | | | | | 2 |
| 35 | | | | | | | 2 |
| 36 | | | | | | | 2 |
| 37 | | | | | | | |

TABLE 18.—*Stand tables for even-aged western hemlock-Sitka spruce in southeastern Alaska*—Continued

SITE INDEX 150

| Diameter class (inches) | Number of trees per acre, by age class— | | | | | | |
|---|---|---|---|---|---|---|---|
| | 30 years | 50 years | 70 years | 90 years | 110 years | 130 years | 150 years |
| Less than 2 | 133 | 5 | | | | | |
| 2 | 147 | 28 | | | | | |
| 3 | 224 | 33 | | | | | |
| 4 | 220 | 54 | 6 | | | | |
| 5 | 216 | 50 | 12 | | | | |
| 6 | 160 | 58 | 13 | | | | |
| 7 | 103 | 57 | 18 | 4 | | | |
| 8 | 77 | 50 | 19 | 9 | | | |
| 9 | 58 | 49 | 23 | 8 | 1 | | |
| 10 | 42 | 44 | 26 | 11 | 5 | | |
| 11 | | 33 | 23 | 12 | 5 | | |
| 12 | | 26 | 23 | 13 | 6 | 4 | |
| 13 | | 21 | 21 | 13 | 7 | 3 | 1 |
| 14 | | 16 | 21 | 14 | 7 | 4 | 3 |
| 15 | | 13 | 17 | 13 | 9 | 5 | 3 |
| 16 | | 13 | 14 | 13 | 9 | 5 | 3 |
| 17 | | 10 | 12 | 13 | 9 | 6 | 4 |
| 18 | | | 10 | 13 | 11 | 7 | 5 |
| 19 | | | 9 | 9 | 8 | 6 | 4 |
| 20 | | | 7 | 7 | 9 | 8 | 6 |
| 21 | | | 6 | 9 | 9 | 7 | 6 |
| 22 | | | 5 | 6 | 8 | 7 | 5 |
| 23 | | | 5 | 5 | 6 | 6 | 6 |
| 24 | | | 3 | 4 | 5 | 6 | 6 |
| 25 | | | | 4 | 5 | 6 | 5 |
| 26 | | | | 3 | 4 | 5 | 6 |
| 27 | | | | 3 | 3 | 4 | 4 |
| 28 | | | | 2 | 3 | 3 | 4 |
| 29 | | | | 2 | 3 | 3 | 4 |
| 30 | | | | | 2 | 3 | 3 |
| 31 | | | | | 2 | 2 | 3 |
| 32 | | | | | 2 | 2 | 2 |
| 33 | | | | | 2 | 2 | 3 |
| 34 | | | | | | 2 | 1 |
| 35 | | | | | | 1 | 2 |
| 36 | | | | | | 2 | 1 |
| 37 | | | | | | 1 | 1 |
| 38 | | | | | | | 1 |
| 39 | | | | | | | 2 |
| 40 | | | | | | | 1 |

## BASIC DATA

The age-class and site-class distribution of the 288 plots represented by the data on which this study is based is shown in table 19. The geographical distribution of the stands represented is shown in figure 1. From 1 to 20 plots were measured in each of these stands.

TABLE 19.—*Distribution of plots by site and age classes*

| Age class | Number of plots, by site-index class— | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 56–65 | 66–75 | 76–85 | 86–95 | 96–105 | 106–115 | 116–125 | 126–135 | 136–145 | 146–155 | Total |
| 15 to 25 years | | | | | 6 | | | | | | 6 |
| 26 to 35 years | | | | 3 | 1 | | | | | | 4 |
| 36 to 45 years | | | | 4 | 0 | 8 | 9 | 4 | | 1 | 26 |
| 46 to 55 years | | | | 4 | 21 | 28 | 3 | 1 | | | 57 |
| 56 to 65 years | | | 9 | 0 | 1 | 3 | 20 | 13 | 2 | | 48 |
| 66 to 75 years | | | 4 | 7 | 4 | 10 | 5 | 4 | 1 | | 35 |
| 76 to 85 years | | 1 | 1 | 2 | 6 | 4 | | | 1 | 1 | 16 |
| 86 to 95 years | | | | 5 | 1 | | | | | | 6 |
| 96 to 105 years | 2 | 7 | | | 16 | 17 | | | | | 42 |
| 106 to 115 years | | | | | | | | | | | |
| 116 to 125 years | | | | | | | 23 | 9 | | | 32 |
| 126 to 135 years | | | | | | | | | | | |
| 136 to 145 years | | | | | | | | | | | |
| 146 to 155 years | | | 1 | 1 | 8 | | | | | | 10 |
| 156 to 165 years | | | | | | | | | | | |
| 166 to 175 years | | | | | | | | | | | |
| 176 to 185 years | | | | | | | | | | | |
| 186 to 195 years | | | | | | 4 | 2 | | | | 6 |
| Total | 2 | 8 | 15 | 26 | 64 | 74 | 62 | 31 | 4 | 2 | 288 |

Altogether, the plots examined in this study numbered 300. Twelve plots were eliminated because their basal area per acre differed from the average basal area per acre for their age and site-index classes by more than two standard deviations.

Table 20 shows the results of checking the yield tables against the plot data from which they were constructed.

TABLE 20.—*Check of yield tables against basic data*

| Item | Deviation | | Item | Deviation | |
|---|---|---|---|---|---|
| | Aggregate | Average | | Aggregate | Average |
| Total stand: | *Percent* | *Percent* | Stand 7 inches or more in diameter at breast height: | *Percent* | *Percent* |
| Number of trees | +0.630 | 25.540 | Board-foot volume (International rule) | −0.992 | 22.390 |
| Basal area | +.497 | 11.336 | Cubic-foot volume (merchantable) | −.690 | 20.820 |
| Diameter at breast height | −.740 | 14.320 | | | |
| Cubic volume | −.250 | 12.890 | | | |

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TECHNICAL BULLETIN NO. 411 MAY 1934

# WESTERN DUCK SICKNESS
# A FORM OF BOTULISM

By

E. R. KALMBACH
Senior Biologist, Division of Food Habits Research
Bureau of Biological Survey

## WITH BACTERIOLOGICAL CONTRIBUTIONS

By

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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UNITED STATES DEPARTMENT OF AGRICULTURE
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# WESTERN DUCK SICKNESS: A FORM OF BOTULISM

By E. R. KALMBACH, *senior biologist, Division of Food Habits Research, Bureau of Biological Survey;* with bacteriological contributions by MILLARD F. GUNDERSON, *Department of Bacteriology and Immunology, University of Minnesota* [1]

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## INTRODUCTION

Duck sickness, a malady affecting not only ducks but also many other groups of wild birds, is today recognized as an outstanding menace to migratory waterfowl in the Western States. The mortality among ducks, coots, gulls, and shore birds of many kinds has been so severe at some points during some years of the past two decades that other factors tending to reduce the numbers of migratory birds in these areas have appeared insignificant (pl. 1, *A* and *B*). In 1910 the extensive mortality among birds in the marshes bordering Great Salt Lake, Utah, first attracted nation-wide attention, and during the years immediately following, the death rate, though reduced, still indicated heavy inroads on western waterfowl. In 1914

[1] A full report of Gunderson's researches, Studies on Western Duck Sickness, a Disease of Wild Water Birds Frequenting Alkaline Lakes, based on work done at the Bureau of Biological Survey laboratory at Klamath Falls, Oreg., during the summer of 1931, and subsequently at the University of Minnesota, was submitted to the graduate faculty of that university as a thesis in partial fulfillment of the requirements for the degree of doctor of philosophy, in June 1932.

the Bureau of Biological Survey inaugurated its first study of the malady, and continued the work in 1915 and 1916. A preliminary report (*70*)[2] in 1915 by Alexander Wetmore, followed by his more extensive publication (*71*) in 1918, summarized the findings to that time. The conclusion reached in that investigation, carried out primarily in the highly saline environment of Great Salt Lake and its contiguous alkali flats, was that "duck sickness in Utah is caused by the toxic action of certain soluble salts found in alkali."

Subsequent years brought to light evidence of the disease at other widely scattered western points, in an area extending from the southern Canadian Provinces to Mexico, and from southwestern Minnesota to the west coast (fig. 1, p. 32). In the main, the distribution of the malady conformed to the region of alkaline waters and soils, yet there appeared no close relationship between the prevalence of the disease and either the concentration or the character of the alkali. There were reported from time to time severe outbreaks in areas in which the supposedly causative salts were present in what appeared to be negligible quantities; conversely, certain bodies of water that held high concentrations of the suspected salts served as havens for waterfowl over considerable periods. Though, in general, outbreaks were associated with periods of high temperature and low stages of water (which logically might be interpreted as indices to a condition of greater alkalinity or salinity), the suddenness with which some outbreaks began and ceased found no corollary in the saline conditions current at the time. Differences were noted also between the general syndrome of duck sickness and its pathology, and that of the toxic action of the suspected salts, as further information became available in the growing literature of that field of toxicology. As time went on, other evidence, much of it less convincing in character, increased a feeling among many sportsmen and other observers of wild life that the cause of duck sickness was not yet definitely established. There were some misgivings also among scientific groups, in view of the accumulating evidence, which indicated, at least in areas distant from the highly saline environment of Great Salt Lake, that some factor or factors other than alkali might be involved, or that several maladies having closely similar symptoms might be responsible for the losses.

To clarify these uncertainties, the Biological Survey renewed its study of the disease in 1927. The studies were not continued in 1928, as there was no marked outbreak until late in fall, but in the following year, 1929, investigations again were resumed and were continued through the summer seasons of 1930 and 1931.

The results, which have removed the problem of duck sickness from the field of chemical toxicology to the realm of bacteriology, are presented in this bulletin. The disease has been associated definitely with the toxin of a common saprophitic bacterium, *Clostridium botulinum*, type C, an organism best known in the United States as a frequent cause of limberneck in poultry and forage poisoning in livestock.

As in other kinds of research, much of the success attained in this study has been dependent upon the facilities for doing the work.

[2] Italic numbers in parentheses refer to Literature Cited, p. 78.

Although field experimentation was conducted far from the fully equipped laboratory that has come to be looked upon as a matter of course in bacteriological research, deficiencies in this respect were compensated for by help of inestimable value rendered by many individuals and organizations interested in the success of the investigation.[3]

## SCOPE OF THE PRESENT INVESTIGATION

The first intensive study of the present investigation was that conducted in 1927 by C. C. Sperry, of the Bureau of Biological Survey. With headquarters at Klamath Falls, Oreg., he made observations in the adjacent area throughout August and September. Although no laboratory facilities were available at that time, Sperry constructed a number of cages in which he conducted his experiments. One of these, of particular significance, is mentioned on page 56.

In the following year (1928) studies were not resumed, since duck sickness did not appear until too late in the season to warrant dispatching an investigator and providing equipment for a period of study that would necessarily be brief. In 1929 actual investigative work was begun at Klamath Falls on June 8 and continued until October 21. In that season a field laboratory (pl. 6, *A*) was established and additional experimental pens were constructed. The laboratory afforded facilities for microscopic work and the preparation of histological specimens, limited chemical analysis of waters, and experimentation in other ways. Attempts were made to produce the disease by feeding birds with natural and synthetic "alkalis"; feeding experiments were undertaken with body tissues of birds dying of the disease, with fermented vegetable matter, and with sarcophagid-fly larvae; and, even in that season, experiments were conducted to determine whether botulism might be the cause of the disease.

Through a cooperative agreement with the Bureau of Animal Industry, Eloise B. Cram, of the Zoological Division, was detailed to the Klamath Falls laboratory from August 5 to September 3, 1929, to study the relation of internal parasites to duck sickness. A résumé of Dr. Cram's findings is presented on page 10. The late C. Dwight Marsh, of the Pathological Division of that Bureau, also inspected the Klamath Falls district (Aug. 25–27, 1929) to learn whether toxic algae might be involved. In the same season

[3] J. C. Boyle and H. P. Bosworth, Jr., of the California-Oregon Power Co., at Klamath Falls, Oreg., kindly made available a 1-room concrete building for use as a laboratory, and land on which to construct experiment pens, and gratuitously supplied electric light and water. To Supt. B. E. Hayden and other representatives of the Bureau of Reclamation at Klamath Falls thanks are due for data on local temperatures and water levels, factors playing an important part in the incidence of duck sickness. Helpful advice in the pursuit of the bacteriological and toxicological aspects of the research was given by Robert G. Green, of the Department of Bacteriology and Immunology of the University of Minnesota; Ivan C. Hall, of the Department of Bacteriology and Public Health of the University of Colorado; and by L. T. Giltner, of the Pathological Division of the Bureau of Animal Industry. James F. Couch, also of the Pathological Division, and Eloise B. Cram, of the Zoological Division, both of the Bureau of Animal Industry, contributed much to the progress of the work while under temporary assignment at the Klamath Falls laboratory. To W. R. Taylor, of the University of Pennsylvania, thanks are due for the identification of algae. To W. H. Meal, manager of the Bear River Club, Brigham, Utah, acknowledgment is made of historical data concerning duck sickness at Great Salt Lake covering the period subsequent to Dr. Wetmore's work. Gratitude is expressed collectively to members of the Bureau of Biological Survey for aid in many lines of the investigation and to numerous correspondents and collaborators of the Bureau in Canada and Mexico and throughout the United States, who have contributed much through written word and by specimens to the total knowledge of duck sickness in its field aspects.

helpful suggestions were offered by B. T. Simms of the Oregon State Agricultural College.

During the winter of 1929–30 an arrangement was made with the Water and Beverage Section of the then Food, Drug, and Insecticide Administration of this Department for detailed analyses of 28 samples of water collected in the Klamath Falls district. These, together with the analyses of 16 samples collected by Sperry in 1927 and others collected earlier by Wetmore, at Great Salt Lake, form the basis of much of the discussion in this report of "alkali" in its relation to duck sickness. In the spring of 1930 a few experiments were conducted at Washington, D.C., to note the effect of certain lead salts and hydrogen sulphide on ducks.

At the beginning of the field work in 1930 (July 1) little more was known of the real cause of duck sickness than at the inauguration of the study in 1927. Some new evidence of a positive character with respect to the toxicity of "alkali" was brought forward in 1929 by Shaw (*60*), yet there was also an ever-increasing doubt as to the adequacy of this postulate in the light of certain field aspects of the malady. Accordingly, with the object of learning more of the role of alkali as a causative factor in the Klamath Falls district, a cooperative arrangement was effected whereby James F. Couch, of the Pathological Division of the Bureau of Animal Industry, was detailed to the Klamath Falls laboratory for the period August 18 to September 8, 1930. Couch's contribution, discussed elsewhere (pp. 16–17), deals largely with the analyses of waters and muds of the sickness and nonsickness areas.

Late in July and during the early part of August 1930 a series of unexpected results attained in experimentally feeding gulls on the body tissues of birds dying of duck sickness focused attention on this aspect of the study. It became evident that something closely akin to duck sickness was being produced through the feeding of such material after it had undergone a certain degree of decomposition. This naturally revived interest in the concept of botulism, which had been considered in earlier work, but for which no demonstrable evidence had been revealed. Other corroborative experiments followed rapidly, and by early October the presence of *Clostridium botulinum*, type C, had been demonstrated by L. T. Giltner in culture material sent to the Bureau of Animal Industry. In the laboratory at Klamath Falls experimental work during the latter part of that season was directed mainly toward determining the relative susceptibility of different species, the suitability of various body tissues as incubating media, the effect of physical and chemical agencies on the toxicity of cultures, and learning what factors appeared to favor toxin production in the field. Late in 1930 there were published two brief articles, one by Kalmbach (*41*), and the other by Giltner and Couch (*25*), in which the season's progress in the duck sickness studies was set forth.

During the winter 1930–31 additional experiments were carried out at Washington, D.C., using chiefly impure cultures brought from duck sickness areas of the West. This work dealt largely with the matter of toxin production in various media, including grains. Further research was directed toward determining the effect of various salts on toxin and toxin production. Despite the convincing charac-

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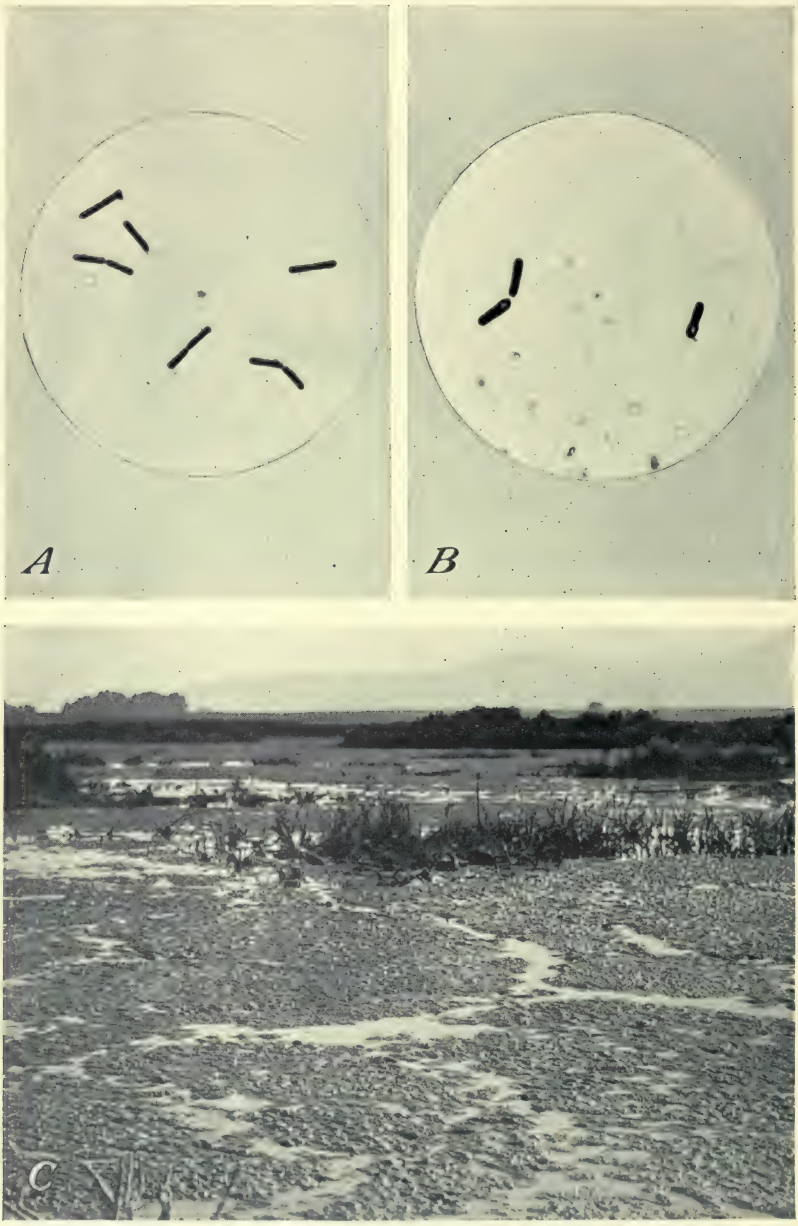
*A*, Typical duck-sickness environment; shallow, stagnant water and alkaline mud flats. *B*, Severe outbreak of the disease on the south side of Willard Spur, Utah, in 1932. On November 12, for 6 to 8 miles, there were 8,000 to 10,000 dead ducks to the mile of shore line. Many additional thousands lay scattered along the shores of Bear River Bay.




B4837M B4836M B35549

*A* and *B*, The causative organism of duck sickness: *A*, A group of vegetative forms of *Clostridium botulinum*, type C. *B*, Two showing subterminal spores. Both × about 1,000. *C*, Beds of filamentous algae play a part in the incidence of duck sickness by preventing water movement, thus intensifying local conditions of decay.

ter of the results attained in the experimental work of 1930 there still remained, at the start of field operations in 1931, the necessity of demonstrating that toxin could be produced under field conditions and might be associated with food and water likely to be ingested by birds.

To attain this objective, accomplished during the summer of 1931, M. F. Gunderson was employed under the disease investigations project of the Bureau of Biological Survey. Later Gunderson continued his studies at the University of Minnesota, and the results of his labors have been incorporated in those sections of this report dealing with the bacteriology of the problem. At the conclusion of field studies in the Klamath Falls district (Oct. 8, 1931), Kalmbach visited several duck-sickness areas in California and Texas, where material was collected for subsequent culturing and identification.

## THE CAUSATIVE ORGANISM, CLOSTRIDIUM BOTULINUM, TYPE C

Duck sickness (botulism) is caused by the toxin, or poison, elaborated by a micro-organism technically known as *Clostridium botulinum*, type C, and is, in fact, a form of food poisoning. This micro-organism is a relatively large, rodlike bacterium, measuring 3$\mu$ to 8$\mu$ in length and 0.5$\mu$ to 0.8$\mu$ in width, and frequently may be found growing in short chains of two or more bacilli connected end to end (pl. 2 *A*). After a period of growth in a suitable medium many of the bacilli form spores, indicated by a swelling of the rod near one end (pl. 2 *B*). It is as a spore that the organism may persist from season to season or even for years, to develop, multiply, and evolve its toxin again when conditions are suitable for growth.

Four principal forms, or strains, of this organism are recognized, designated as types A, B, C, and D (*48*). Types A and B, of wide distribution both in the New and Old Worlds (*46*, *47*) are the ones involved in human botulism. Their toxins are among the most deadly known. Both have entered the picture of human medicine through the generation of their toxins in imperfectly preserved foods, and when these foods have been made available to domestic birds and mammals, these too have succumbed. Chickens, however, are relatively resistant to the toxin of type B.

Type C, the form involved in the present study, also is of wide distribution and, of all the forms, plays the most important role in the destruction of wild and domestic birds and animals. In North America it is the cause of duck sickness in wild fowl, forage poisoning among livestock, and a certain mortality among domestic poultry (*3*, *26*); in Australia and Tasmania this, or a very closely related form, is the cause of the malady known as bulbar paralysis, or midland cattle disease (*58*); in South Africa, where it is known to affect cattle, horses, goats, domestic ducks, and even ostriches, it is the causative factor of the dread lamsiekte (*65*, *66*). It is reported to occur in Europe (*47*), and if the malady among wild fowl reported by Wetmore in Uruguay (p. 32) is due to the same organism, South America also must be included in its broad range. Two variants of type C have been designated as $C_\alpha$ and $C_\beta$, by Gunnison and Meyer (*31*) on the basis of certain bacteriological differences.

The form responsible for duck sickness in this country recently has been determined by Gunnison and Coleman (*29*) to be of the variant $C_\alpha$.

Type D, closely related to type C, occurs with the latter in South Africa, also as a causative factor of lamsiekte among cattle.

Whereas the originally described form of *Clostridium botulinum*, apparently a type B form, has been known since 1896 (*20*) and the literature dealing with it and the other human strain, type A, is voluminous, our knowledge of type C, now demonstrated to be the cause of duck sickness, dates only from 1922, when Ida A. Bengtson, of the United States Hygienic Laboratory, isolated and described it from the larvae of carrion flies (*2*). In 1924 she published a more extensive paper dealing with this particular strain (*3*), but at that time no evidence had come to light indicating that the organism was connected in any way with duck sickness.

Although the four types mentioned differ one from another in the manner in which they grow in various culture media; in the effect of their toxin on different animals, including man; in their reaction to the antitoxins of the respective types; and in other ways, all require essentially the same conditions for growth and development of their toxin. All are known as anaerobes, that is, organisms that thrive only in media or under conditions from which oxygen has been excluded. Likewise all are saprophytes, living and producing toxin in the presence of dead organic matter, animal or vegetable. In other words, the various forms of *Clostridium botulinum*, including the type that produces the duck sickness, are organisms associated with decay, and their toxins are in a sense products of decay. It must not be inferred from this, however, that all decaying material is toxic—only that infected with *C. botulinum* (and a few other organisms not pertinent to this discussion) need be viewed with concern.

In distinction from the causative factors of certain infectious diseases, bacteria of the species *Clostridium botulinum* do not thrive in the living body, and their rodlike bacilli or the minute spores, washed free of all toxin, may even be eaten by birds (at least in doses that are not excessive) without ill effects. It is the preformed toxin, developed outside the body of the bird, and that alone, that produces the disease. The malady can be contracted only through food or water assimilation. It cannot be imparted from one living bird to another. For this reason duck sickness is not contagious.

The extent of toxin production is controlled by a number of factors and conditions. There must, in the first place, be a suitable medium and a deficiency of air (oxygen). Temperature must be kept within certain limits: Earlier investigations with types A and B *botulinum* revealed a temperature range from 28° to 37.5° C. (82.4° to 99.5° F.) for rapid toxin production (*5*), but later studies placed the optimum for type C, derived from duck-sickness cases, at 37° C. (*29*). An alkaline condition is looked upon as being more favorable to growth than one that is neutral or acid. At the same time preformed toxin may be affected adversely in nature by such factors as extreme alkalinity or salinity, light, dessication, or air. In the laboratory a temperature of 80° C. (176° F.) maintained for 30

minutes destroyed the toxin of a type C strain, and boiling for an hour destroyed most spores (*3*).

Dispersal of the organism may take place in many ways. Sarcophagous insects are common vectors; moving water easily may transport organic matter laden with the bacteria or their spores; and even the winds may carry particles of soil or other material to which the microscopic spores may be attached. Birds themselves, because of their frequenting infected areas, may transport the organism with mud or vegetation adhering to feet or plumage. It is even likely that ducks that have ingested lethal doses of the toxin may continue on their migration for many miles before incipient paralysis halts their progress. Then, should they die, their decaying bodies, acting as media, may become centers of other areas of infection. Various wild and domestic mammals, as well as man himself, also may become accidental carriers of the organism in traveling from place to place.

## EARLIER THEORIES AS TO CAUSE

The expression "earlier theories" is applied to all concepts of duck sickness prior to the demonstration of botulism by the present investigation. With respect to some of these concepts, particularly those involving infectious bacterial disease, parasitism, and "alkali" toxicity, the Bureau of Biological Survey, in cooperation with other bureaus of the Department of Agriculture, has made considerable contributions, both in its earlier studies (1914–16) and in those of the present investigation previous to August 1930.

### INDUSTRIAL WASTE AND POLLUTION

Among the earliest of the theories advanced to explain duck sickness was that of chemical pollution of waters by industrial waste. It was surmised that sulphur fumes from the great smelters near Salt Lake City were absorbed by the waters of streams and marshes to an extent sufficient to make these toxic to birds. The theory was weakened by the fact that duck sickness has occurred in typical and virulent form in areas where smelters do not exist. Furthermore, the syndromes of intoxication by sulphurous and sulphuric acids and by arsenic (another element credited with the cause of the disease), and the pathological lesions produced by them, do not correspond with those of duck sickness. Conclusions in this respect are based on experimental work in 1915 by Wetmore (*70, p. 6*) at Great Salt Lake as well as on the researches of toxicologists elsewhere. Attention may be called to the prevalence of the disease in such environments as Lake Newell, Alberta, Lake Malheur, Oreg., Tule Lake, Calif., and the "tanks" in the Panhandle of Texas, as an indication that, at least in those localities, industrial pollution plays no major part in the production of the disease.

Similarly, Wetmore (*71, p. 14*) pointed out that, although sugar refineries were located on each of three rivers in Utah at the outlets of which duck sickness had been prevalent, the seasonal discharge of these plants did not synchronize with the incidence of the disease. Mortality ceased while the mills were still in operation. These observations discount the likelihood of finding a direct and immedi-

ately acting causative factor in such discharges, but they do not explain away the possibility that such refuse, rich in organic matter, may later become a medium for toxin production under suitable conditions of alkalinity, temperature, and anaerobiosis (see p. 67).

Early in the history of the duck-sickness studies in Utah, it was alleged that organic pollution in the form of sewage from Salt Lake City was a causative factor, but this explanation also lost validity when the disease was later discovered at an increasing number of other points where there was no human pollution. There is, however, as in the case of discharges from sugar refineries, the possibility that sewage may increase locally the volume of toxin-producing media. More bacteriological research is necessary on these points.

### LEAD POISONING

Although the idea of lead poisoning has not been seriously advanced as an explanation of true duck sickness, the two maladies have occurred simultaneously in the same area. At such times confusion may result in differentiating them, and birds apparently affected by duck sickness may in fact be suffering from lead poisoning. A judgment based merely on inability of the birds to fly or to walk is inadequate. A fuller diagnosis will leave no doubt as to the identity of the malady concerned. Points of difference between the two maladies were detected and defined by Wetmore in the course of his studies in Utah in 1914–16 (*72*). He found that birds with lead poisoning have good appetites and continue to feed even though the gizzard, by reason of its paralysis, fails to triturate the food, and that this often leads to a great distention of the proventriculus. In duck sickness a loss of appetite is characteristic. The percentage of recovery from lead poisoning is low, and improvement is greatly retarded, whereas in duck sickness there is a high percentage of recovery and sometimes this is almost spontaneous. Paralysis of the nictitating membrane is not a symptom of lead poisoning, though in duck sickness it is common. In lead poisoning, in addition to a brilliant green discoloration of the gizzard contents and a distention of the gall bladder, one may frequently find the telltale shot in the stomach itself.

### GASES

The presence of methane, hydrogen sulphide, and other gases in duck-sickness areas has given rise to the belief, quite prevalent in some places, that duck sickness is produced by the inhalation of gaseous toxins. There is little basis for this belief other than the fact that these gases are present, and that in sufficient concentration they are toxic. The marked dissimilarity, however, between the symptoms of duck sickness and those resulting from the inhalation of these gases precludes serious consideration of the latter as a factor. As a check against a report that paralysis of the nictitating membrane, a characteristic symptom of duck sickness, may be induced by hydrogen sulphide, asphyxiation experiments on ducks were conducted, but in no case was paralysis of the nictitating membrane observed. Furthermore, as was to be expected, the whole syndrome of hydrogen-sulphide intoxication is so radically different from that of duck sickness that the two cannot be confused or considered to have anything pathologically in common.

### BACTERIAL INFECTION

The concept of a bacterially produced duck disease dates back to the first investigations. Much of the early experimental work was devoted to attempts to produce or transmit the malady by one or another of the methods commonly employed in conveying bacterial infections. Every attempt of this kind, however, met with failure. Wetmore in 1918, related some of his experiences in the following words (*71, p. 13*):

> Healthy birds were confined with sick birds or were given grain treated freshly with feces taken from affected individuals. Some were fed forcibly on fragments of organs or the entire stomach and intestinal content of sick birds. The mucous lachrymal discharge in birds far gone was transmitted to the eyes of some. Intravenous and hypodermic transfusions of blood were made. All these experiments gave negative results.

Specimens sent to the Bureau of Animal Industry as early as 1914 were closely examined, but no diagnostic lesions were revealed. Numerous inoculations made from different organs of the sick birds, both on culture media and into experimental animals, failed to disclose any organism that might be regarded as the causative agent of the disease (*70, p. 5*).

Symptoms were carefully noted with respect to similarity to the syndrome of the avian bacterial diseases then prevalent. It was observed that to a certain degree avian cholera (caused by *Pasteurella avicida*) resembled duck sickness in that there was a general depression that might be mistaken for paralysis, a diarrhea, a pronounced thirst (prevalent in birds recovering from duck sickness), labored breathing, and, shortly before death, complete prostration. Discrepancies existed, however, in the above-normal temperature in avian cholera as against the uniformly subnormal temperature in duck sickness, and in the characteristic hemorrhagic areas present on the surface of the heart in avian cholera compared with the absence of the pronounced lesions in duck sickness. Furthermore, inability to transmit the disease by the means employed in the experimental work afforded added evidence against cholera as the cause. In fact it was the lack of infectiousness, the lowered body temperature, and absence of the characteristic post-mortem aspects of duck sickness that distinguished it from all other avian bacterial diseases generally known at the time.

Failure to demonstrate bacterial infection marked the efforts of H. Van Roekel in California in 1929 (*69*). Shaw, in 1930, stated: "Attempts to culture a causative organism from the tissues and intestinal tracts of the diseased birds gave negative results" (*62, p. 564*). Experiments aiming to reproduce the disease by placing birds in a suspected pathogenic environment also were inconclusive.

Despite failures in the earlier experiments and despite the fact that, throughout the years, thousands of sick and convalescing birds had been kept in intimate contact with healthy stock or with birds that had fully recovered without having transmitted the disease, the idea of some obscure bacterial trouble was not wholly discarded even when the investigation was resumed in 1927.

As late as the field season of 1930 a number of inoculation experiments involving the use of blood serum and brain emulsion of afflicted birds were conducted. Doses of 0.5 to 2.0 cc of the serum,

administered subcutaneously beneath the wing or intraperitoneally, failed to affect pintails and mallards; and injections of brain emulsion varying from 0.1 (injected directly into the cerebrum) to 0.5 cc (injected just anterior to the atlas vertebra) gave negative results with pintails. When it became evident later that the malady was caused by the toxin of a saprophyte, generated under conditions of decay outside the body, attempts to convey this noncontagious disease from bird to bird were discontinued.

### PARASITES

The possibility of parasitic infestation also has been considered in attempts to solve the mystery of duck sickness. Coccidia found in the intestinal tract of ducks in the course of early examinations were looked upon with suspicion, but this was not substantiated by later studies. Limited study of parasitic nematodes at Great Salt Lake also failed to disclose positive evidence (*70, p. 5*). In later years observations in California militated further against the possibility of parasites being to blame. E. C. O'Roke, then conducting investigations for the Division of Fish and Game of the California Department of Natural Resources, came to the conclusion: "From the standpoint of intestinal parasites, the survey thus far has disclosed no apparent relationships existing between duck sickness and the presence of parasites" (*53, p. 294*).

Dr. Cram contributed substantially to the knowledge of parasites and their negative relationship to duck sickness in the course of a month's field research at the Klamath Falls laboratory in 1929 and in subsequent study of the material collected. Detailed observations were made on a total of 41 birds—including 18 pintails, 10 California gulls, 3 avocets, 2 western sandpipers, 2 Wilson's phalaropes, and 1 each of 6 other species. The report [4] shows that—

> At post mortem examination respiratory and digestive tracts and the body cavities were scrutinized for the presence of worm parasites, and smears were made from the respiratory, digestive, excretory, and circulatory systems for microscopical examination for protozoan parasites.
>
> Parasites were found to be present in a high percentage of the birds examined and often in heavy infestations. However, the fact that control, that is, unaffected, birds also showed parasites; that, in the cases in which a considerable number of sick birds of one species were available for examination, a few of the birds showed no parasites, although they showed the same symptoms as the parasitized birds; and, finally, the fact that the parasites found in the sick birds represented a wide variety of species, with no indication of the predominance of any one occurring throughout the various species of birds, all indicate that duck sickness is not correlated with parasitic infestation.

It was determined, however, that, in several instances, parasitism was of a degree that indicated definite injury to the bird host. These injuries included the formation of necrotic areas in the glandular and corneous walls of the proventriculus and the gizzard, respectively, and the formation of tumors at the junction of these organs; inflammation and thickening of the wall of the small intestine were also noted. Although no experiments were made in this investigation to determine the effect of lesions in the alimentary tract on the

[4] CRAM, E. B. REPORT ON AN INVESTIGATION OF THE RELATION OF PARASITES TO "DUCK SICKNESS" IN THE KLAMATH FALLS REGION. 1929. (Manuscript on file in Bureau of Biological Survey.)

assimilation of *botulinum* toxin, Graham and Boughton (*26, p. 23*) have referred to the possibilities in this direction. By the puncturing of the stomach or intestinal walls, parasites may play a secondary or predisposing part in duck sickness.

At Lake Malheur, Lake Newell, and at other points, observers have noted, in the course of duck-sickness outbreaks, a prevalence of leeches, these clinging to and even clogging the nostrils and trachea of disabled birds. To one unfamiliar with the course of events leading to this condition, leeches might appear to be the causative factor in the birds' disability. Although the annelids may add greatly to the discomfort of such helpless birds and probably hasten the death of many, they cannot be looked upon as the primary cause of the disease. The presence of these parasites is a result, not the cause of the malady, since the birds, hopelessly paralyzed and often prostrate, cannot prevent the leeches attaching themselves. Total absence of leeches in typical outbreaks of duck sickness at other points militates against the possibility of their being causative factors.

Mention may be made of the observed presence of dead snails surrounding the carcasses of birds that had died of duck sickness. Although the phenomenon was not noted about Klamath Falls, it was reported common at Lake Malheur in the outbreak of 1925, and at that time there was a popular surmise that snails were playing the role of intermediate host for some parasite. While the present understanding of duck sickness completely eliminates this concept, the presence of the snails nevertheless may have had peculiar significance. It is possible that these mollusks, dying from a lack of oxygen or other cause, may have served to produce the toxic material later ingested by ducks and shore birds. In this manner snails may serve as secondary causative factors of the disease, though not intermediate parasitic hosts.

### DIETARY DEFICIENCY

That duck sickness is a nutritional malady has been contended by some who have endeavored to interpret the symptoms. L. Alva Lewis, a proponent of the idea, asserted duck sickness among waterfowl to be the direct result of a diet characterized by a marked excess of wheat and other grain, with a corresponding scarcity of green foods.[5] The resultant excess of vitamin B and deficiency of vitamins A and C were looked upon as the causative factor of the paralysis and other symptoms. It was held that the harvesting of the grain crop late in summer and a coincident decrease in the supply of green food were responsible for the dietary upset.

Polyneuritis, a nutritional disease among domestic fowl subsisting on a diet deficient in the water-soluble vitamin B, may be mentioned, not as being involved in any disorder of wild birds, but because of the similarity of some of its symptoms to those of duck sickness. There is a subnormal temperature, as in botulism; a progressive paralysis, the first manifestation of which is an unsteadiness on the feet, with a tendency to lean forward onto the toes (p. 48); a leg weakness, revealed at the tibiotarsal joint and causing the bird to drop suddenly when squatting; and, at the end, utter prostration.

[5] LEWIS, L. A. NEUROTIC DYSTROPHY AMONG DUCKS OF THE FAR WEST. 1927. (Manuscript report submitted to Bureau of Biological Survey.)

Despite the marked similarity of some of the symptoms of duck sickness and those of a dietary upset, the nutritional-disease theory loses validity when certain attendant factors are considered. Duck sickness has frequently appeared when green food in the form of *Potamogeton* and other submerged vegetation was plentiful. It also has ceased when grain still was being eaten and no additional supplies of green food were available. The malady affects alike such widely divergent forms as the highly vegetarian ducks, the insectivorous shore birds, and the omnivorous magpie. Moreover, a high percentage of the sick birds recover without correction of any suspected deficiencies in diet. In fact, the thousands of birds that have been salvaged (pl. 6, *B*) in years past have in the main been fed on rations more deficient in vitamins A and C than was their lot under field conditions. Furthermore, to test the validity of the nutritional-disease theory, Sperry in 1927 demonstrated that mallards and pintails, sick with the disease, effected recovery as quickly and as completely when fed on an exclusive diet of wheat (for a week or 10 days) as when given a mixed ration.[6] In the normal process of recovery, the desire for food of any kind is one of the last of the impaired impulses to be regained by birds affected with duck sickness, and for this reason its character can play, at best, a minor and delayed function in the process of recuperation.

### TOXIC ALGAE

The hypothesis that algae may be involved as causative factors in duck sickness acquired a degree of plausibility from observations made in the course of the outbreak at Lake Newell, in 1925 (*51*). J. A. Munro noted that a marked change had taken place in the character of the submerged flora since his earlier observations in 1921, and that a luxuriant stand of *Potamogeton* had to a large extent been displaced by masses of blue-green algae, which decomposed later in the summer and accumulated in vile-smelling masses in shallow and sheltered portions of the lake. Such a condition of decay did not exist in the following year, when the water level had lowered, and the malady did not reappear.

The presence of extensive algal growth of both the blue-green (Myxophyceae) and the green algae (Chlorophyceae) has been noted at other points coincidentally with outbreaks of duck sickness. In 1928 a prevalence of what were apparently blue-green algae was observed at the American Falls Reservoir, Power County, Idaho, during a period when duck sickness prevailed. In the following year a similar condition was noted at Long Lake, Kidder County, N.Dak., during the peak of an outbreak of the disease. In the Klamath Falls district, filamentous green algae (Chlorophyceae) have dominated the submerged flora of some of the bodies of water where the sickness has occurred. Late in summer these beds, rising to the surface, cover extensive areas, and by their greenish yellow coloration add much to the brilliance of the scene (pl. 2, *C*).

In August 1929, Marsh visited Tule Lake, near the seasonal peak of the outbreak of duck sickness, to learn what part algae, particu-

[6] SPERRY, C. C. REPORT ON DUCK SICKNESS IN SOUTHERN OREGON AND NORTHERN CALIFORNIA IN THE SUMMER OF 1927. 1927. (Manuscript in files of Bureau of Biological Survey.)

larly those of the genus *Anabaena*, known to be toxic at times, may play in duck sickness. The center of the malady was on overflowed wheatland, at the northwest corner of the lake, and in that area the suspected blue-green algae were scarce. From observations made it was concluded that the possibility of algal intoxication was remote.

Algae may, however, play a secondary role in the incidence of the disease. These beds are the feeding grounds of many of the smaller shore birds (pp. 38–39). There the western and least sandpipers obtain the hydrophilid larvae, which, after death, may harbor the toxin of botulism (p. 58). It is in these tangled masses of algae also that many of the afflicted birds become imprisoned and lie exposed to the heat of the midday sun. There is the possibility (which at present has no proof) that the masses of algae cast up on mud flats may themselves serve, under suitable conditions, as incubating media for the bacteria of duck sickness. That they harbor in their skeins many minute organisms that may contribute to toxin production there is little doubt, and the impairment of water movement by dense algal mats tends to intensify conditions of decay and to prevent the dispersal or dilution of preformed toxin.

### ALKALI TOXICITY [7]

The concept of toxic alkali as the causative factor of duck sickness was generally accepted as the result of experimental work conducted prior to 1918 by Wetmore, mainly in the highly saline environment of Great Salt Lake (*70*, *71*). Although toxic alkali was looked upon with suspicion by Wetmore as early as 1915 it was not until the completion of his work that he definitely stated:

> By actual experiment it has been found that the duck sickness may be caused by the chlorides of calcium and magnesium. Experiments have indicated that other salts may be incriminated in Utah and elsewhere, but this statement is made with reserve, as it has not yet been definitely established (*71, p. 15*).

It is apparent from the foregoing that Wetmore felt that he had reproduced the syndrome of duck sickness in experimental birds by feeding them on suspected salts. Many other highly suggestive factors contributed to the conviction, quite generally entertained during the subsequent decade, that toxic alkali was to blame. In the first place duck sickness was, in a general way, associated with alkaline areas, and the outbreaks occurring in the San Joaquin Valley of California were looked upon as paralleling, in an etiological way, the malady at Great Salt Lake. The disease appeared to synchronize with circumstances that could be interpreted either as an increase in alkali or a more favorable opportunity for birds to ingest toxic salts. In addition there was suggestive evidence that a high percentage of sick birds transferred from an alkaline environment to one where they had access to fresh water recovered within a few days.

A number of other factors militating against an infectious bacterial explanation of the malady lent credence to the alkali theory in a negative way. Among these was the fact that the disease numbered among its victims many species of birds having a diversity of food habits and life histories, a condition ordinarily not encountered in infectious diseases and parasitism, yet strongly indicative of some

[7] The word "alkali" as used in this bulletin, refers to the combination of various salts, usually alkaline in reaction, found in western waters, muds, and soils.

widespread intoxication. Furthermore, the affected birds usually were in good flesh and, with the exception of a certain congestion of the arteries of the intestine, considered to be due to the irritant action of alkali, no characteristic lesions were evident.

Although as time went on, there were certain misgivings as to the adequacy of the alkali theory, it had in its favor a measure of experimental proof and a degree of plausibility possessed by no other single idea. When circumstances finally led to a resumption of investigative work by the Biological Survey (p. 2) the theory of alkali toxicity became a primary one to be proved or disproved in the light of new conditions and further direct experimental work.

In the analysis that follows, much of which deals with evidence against the postulate that duck sickness is caused by the toxicity of certain salts, full cognizance has been taken of the fact that some natural salts are toxic and under certain conditions may result in avian mortality.

## CHARACTER OF WATERS

An analysis of alkaline waters with reference to duck sickness is presented in table 1, which shows in the form of percentages of the whole, the proportions of the bases and acid radicals of the saline components of 10 samples of water and 1 of mud extract obtained, with one exception, at the scenes of typical duck sickness. The single exception was that from Owens Lake, Calif., where the mortality of early days was at one time considered to be duck sickness, but on which later developments have thrown some doubt (p. 25). It is evident that even in a single area there may be considerable variation in the character and concentration of salines in different samples of water collected. For instance, at an irrigation sump south of Klamath Falls, total salt concentrations were recorded of from 1,700 to more than 200,000 parts per million, and variations in the chlorine radical from 1.52 to 7.95 percent. The analyses here discussed have been selected, however, as representative.

TABLE 1.—*Analyses of samples of western alkaline waters taken chiefly at scenes of typical duck sickness*

[The proportions of the various basic and acid radicals rather than those of hypothetical salts have been used in this table as a means of rational comparison. The figures indicate percentages of total anhydrous, inorganic solids. The composition of these waters in relation to the prevalence of duck sickness is discussed on pp. 14 to 17]

| Sample | State | Percentages of component parts | | | | | | | | | | Total salinity (p. p. m.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Cl | $SO_4$ | $HCO_3$ | Na | K | Ca | Mg | $SiO_2$ | $Fe_2O_3$-$Al_2O_3$ | Miscellaneous | |
| A | Utah | 32.36 | 8.16 | [1] 21.53 | [2] 20.54 | ------ | 10.12 | 4.76 | ------ | 2.53 | ------ | 637 |
| B | do | 55.53 | 7.34 | .23 | 32.56 | ------ | .97 | 3.15 | ------ | -------- | 0.22 | 102,658 |
| C | do | 34.03 | 5.11 | 33.38 | 10.55 | ------ | 7.32 | 9.61 | ------ | -------- | ------ | [3] |
| D | Oregon | 3.45 | 3.83 | 62.82 | 1.15 | ------ | 15.70 | 4.60 | 6.13 | 2.32 | ------ | 261 |
| E | do | 4.55 | 7.64 | [1] 44.63 | 24.17 | 5.58 | 5.58 | 4.13 | 2.89 | -------- | .83 | 484 |
| F | North Dakota | 1.67 | 25.32 | 36.06 | 26.62 | ------ | .66 | 2.51 | .08 | -------- | [1] 7.08 | 2,710 |
| G | South Dakota | 1.77 | 46.29 | 23.74 | 17.51 | ------ | 1.63 | 7.44 | ------ | -------- | 1.62 | 1,696 |
| H | Oregon | 6.58 | 60.39 | 2.79 | 23.94 | ------ | 1.76 | 4.37 | ------ | -------- | .17 | 38,326 |
| I | do | 3.80 | .28 | 70.17 | 17.57 | ------ | 5.13 | 2.94 | ------ | -------- | .11 | 1,053 |
| J | California | 4.01 | 9.80 | 58.92 | 18.54 | ------ | 5.90 | 1.89 | ------ | .82 | .12 | 847 |
| K | do | 24.82 | 9.95 | 24.55 | 38.09 | 1.62 | .02 | .01 | .14 | .04 | .78 | 213,700 |

[1] Normal carbonate.
[2] And potassium.
[3] Not computed; see description of sample.

The samples of water were obtained as follows:

A. Near mouth of Bear River at Corrine, Utah. Analysis received from Southern Pacific Railroad (*9, p. 158*).

B. Mouth of Weber River, Utah. Collected by Wetmore subsequent to the peak of duck-sickness outbreak. Examination by Bureau of Chemistry and Soils, United States Department of Agriculture.

C. Water soluble material from muds in sickness areas on the Bear River Delta. Collected by Wetmore. Examination by Bureau of Chemistry and Soils.

D. Mouth of Blitzen River, Lake Malheur, Oreg. Collected by Ray C. Steele while duck sickness was prevalent in August 1926. Examination by Bureau of Chemistry and Soils.

E. Lake Malheur, Oreg. (*9, p. 163*).

F. Long Lake, Kidder County, N.Dak. Collected in August 1917. Examination by Bureau of Chemistry, United States Department of Agriculture.

G. Lake Poinsett, Hamlin County, S.Dak. Collected September 12, 1929, by F. M. Uhler while an outbreak of duck sickness was on the wane. Examination by the Water and Beverage Section, Food, Drug, and Insecticide Administration, United States Department of Agriculture.

H. Shallow pool at Government sump, 10 miles south of Klamath Falls, Oreg. Collected by Sperry in 1927. Examination by the Food, Drug, and Insecticide Administration.

I. Flooded Field near Keno, Oreg. Collected by Sperry in 1927 during a duck sickness outbreak. Examination by the Food, Drug, and Insecticide Administration.

J. Lower Klamath Lake, Siskiyou County, Calif. Collected by Sperry during a limited duck sickness outbreak. Examination by the Food, Drug, and Insecticide Administration.

K. Owens Lake, Calif. (*9, p. 162*). Sample taken in Auugst 1905. Analysis by C. H. Stone.

Despite the fact that all but one of these samples came from areas in which duck sickness was prevalent or has occurred, there is wide diversity in the proportions of the saline components. Even ions that theoretically may be combined to form the chlorides of calcium and magnesium, formerly considered causative factors of the disease, are by no means uniform or conspicuous in the several samples. Sample D, for instance, collected at Lake Malheur during a disastrous outbreak, though containing calcium in moderate proportion (15.7 percent), had little chlorine, and the total salinity (261 p.p.m.) was so low as to make the solution as a whole innocuous. Samples A and C (the latter a water extract from mud), collected at Great Salt Lake, revealed calcium, magnesium, and chlorine ions in fair proportions, yet even though these were combined to form chlorides of calcium and magnesium, they still would comprise a minor part of the saline complex, and could be considered toxic only in high concentrations. In all other samples these two chlorides formed even smaller proportions. In no case did calcium and magnesium chlorides dominate the saline content.

The other ions that in one form or another might be considered toxic to birds show great variation in the samples. The proportions of sodium, carbonate (bicarbonate), and sulphate ions as well as chlorine (previously discussed in combination with calcium and magnesium) fluctuate from a position of dominance to one of insignificance. There appears to be no salt or combination of ions that is a characteristic of the alkaline waters collected in these widely separated duck-sickness areas.

For a study of the alkaline waters of the Klamath Falls section, the analyses of 26 samples are available in addition to the 3 presented

in table 1. These were collected at Tule Lake, at the Government sump 10 miles south of Klamath Falls, and from various adjacent ponds, canals, or flooded fields.

Of the 26 samples, 13 were collected in duck-sickness areas, either just before, during, or just after an outbreak; the other 13 were collected under circumstances not intimately associated with the disease. Data concerning the proportions of the sodium, magnesium, calcium, and chlorine ions in these two groups are presented in table 2.

TABLE 2.—*Sodium, magnesium, calcium, and chlorine ions (expressed as percentages of total soluble salts) in samples of water from duck-sickness areas and from areas free of the disease, based on the analysis of 26 samples collected mainly in the vicinity of Klamath Falls, Oreg.*

| Source of samples | Samples | Na | Mg | Ca | Cl |
|---|---|---|---|---|---|
| | *Number* | *Percent* | *Percent* | *Percent* | *Percent* |
| From duck-sickness areas | 13 | 16.02 | 2.01 | 6.27 | 2.61 |
| From areas free of sickness | 13 | 17.93 | 4.99 | 3.81 | 4.39 |

It is apparent that none of these waters of the Klamath Falls section is dominated by the chlorine ion, as the average percentage of this element in the whole group of samples was only 3.5. The percentages of chlorine, sodium, and magnesium were greater in the waters from nonsickness areas, while the reverse was true of calcium. Such conditions might be construed as confirmatory of the alkali theory insofar as it applies to the toxicity of calcium chloride, but it is to be remembered that the differences with respect to the salts in the sickness and nonsickness areas are merely in degree. When it is realized that the whole matter is subject also to the highly variable factor of concentration, these differences in percentages in what are in fact minor elements in the saline complex do not appear pronounced enough to account for the presence, or the total absence, as the case may be, of an epizootic.

In this discussion of the character of salts in sickness and nonsickness areas it is fitting to call attention to the published findings of Shaw (*61*) in California, that soils from certain disease areas contained a relatively high percentage of nitrate ions, while comparable soils from nondisease areas revealed very little. This was interpreted as being highly suggestive of his contention that toxicity may be increased by the addition of nitrate ions to what otherwise might be more or less harmless saline combinations (*60*). At the time these ideas were advanced the whole matter was treated from a toxicological standpoint, and, although it was recognized that nitrates often are the end product of bacterial processes, the significance of this interpretation in relation to the real cause of duck sickness was not then appreciated.

In the work at Klamath Falls, effort was made to repeat Shaw's experimental work, which had been conducted largely in California. Couch gave considerable attention to this aspect of the case and made numerous tests for nitrites and nitrates in the muds of sickness and nonsickness areas.

In the determinations made during this investigation the results showed that the largest proportion of nitrates was obtained from a pond [Largent's] where there was no outbreak of the disease this year (1930) and smaller amounts occurred in areas where the disease was in active progress.[7a]

Appraisal of the character of waters in sickness and nonsickness areas has yielded little to confirm the earlier concept of alkali toxicity postulated by Wetmore and its variant advanced by Shaw. No direct synchrony between the character of alkali and the incidence of duck sickness was revealed except that brought out by Shaw, which is subject to more logical interpretation on bacteriological than toxicological grounds. There remained, however, the necessity of determining, approximately at least, what concentrations of salines commonly found in these waters, are actually toxic to waterfowl, and hence a potential danger.

### TOXIC CONCENTRATIONS

Ingested in sufficient quantity, sodium chloride is toxic to birds. Experimental work has demonstrated that this salt, administered daily, at the rate of 4 g per kilogram of body weight, is close to the minimum lethal dose for a chicken weighing 3 to 5 pounds (*50*). It has been shown by Heller and Larwood (*34*) that Epsom salt (magnesium sulphate), a common constituent of western alkalis, has a retarding effect on growth of small mammals when used in drinking water in concentrations of 15,000 p.p.m., and that it is decidedly toxic in concentrations of 25,000 p.p.m. Calcium chloride is even more toxic, yet in weak solutions (2,000 p.p.m.) this salt was found harmless when used in drinking water of white rats (*49*). "The chlorine ion appears to be more toxic than either the carbonate or the sulphate ion. The calcium and magnesium ions are more harmful than the sodium ion" (*34*). Shaw (*60*) has demonstrated experimentally the toxicity to ducks of sodium chloride, magnesium chloride, and calcium chloride as well as certain mixtures of these and other salts.

In the course of this investigation it was demonstrated, through an experiment conducted in pens erected over a natural pool of alkaline water, that saline solutions of the character prevalent about Klamath Falls are highly toxic to several species of birds whenever the concentration is as great as 25,000 p.p.m., provided such solutions are the sole source of drinking water. In character the dissolved salts were largely sulphates with carbonates and bicarbonates in moderate proportions and chlorides forming a negligible part. Sodium was the dominant base. The birds subjected to such experimentation included gulls of two species, coots, and redhead and mallard ducks. The same saline solutions in concentrations of 5,000 or 2,000 p.p.m. appeared not to be harmful.

Seventeen other experiments were conducted to learn more of the character and concentration of alkali needed to produce intoxication among ducks using the solutions as drinking water. In eight of these the birds died apparently from the toxic effect of the dissolved salts. Death occurred in every completed experiment in

[7a] COUCH, JAMES F. REPORT OF INVESTIGATION OF SO-CALLED ALKALI POISONING OF DUCKS AT KLAMATH FALLS, OREG., IN 1930: RESULTS OF ANALYSES AND EXPERIMENTS. 1930. (Copy of manuscript on file in Bureau of Biological Survey.)

which the solution approached the salt concentration of ocean water (31,000 to 36,000 p.p.m.), and in one instance a concentration of 26,000 to 27,000 p.p.m. killed a bird that had been taking it only 2 days. In two experiments in which higher concentrations were used (80,000 and 200,000 p.p.m., respectively), the birds refused to drink, indicating that there is a point at which ducks may prefer to die of thirst rather than take the exceedingly toxic waters. On the other hand, solutions containing salts in a concentration of 3,353 p.p.m., half again as strong as the highest concentration recorded for the open water of Tule Lake, failed to affect birds drinking it for 7 days.

Knowing the minimum lethal concentration (for birds) of the saline solutions prevalent in the Klamath district (20,000 to 25,000 p.p.m.), it is possible to appraise conditions more definitely with respect to the likelihood of birds ingesting lethal doses under field conditions. The highest concentration of salts recorded for any water sample in the immediate vicinity of Tule Lake was 8,079 p.p.m. This sample was collected in a small depression adjacent to the lake at a time when the water table was slowly rising and absorbing the encrusted surface alkali.

Something of the harmlessness, even to birds afflicted with duck sickness, of saline solutions containing as much as 11,500 p.p.m. of dissolved salts, was learned at the Bear River (Utah) Migratory Bird Refuge during the summer of 1932. In that season 1,819 sick birds were gathered and placed in an enclosure where, for bathing and drinking purposes, they had access to a pool formed by an artesian well. This water contained sodium chloride in the concentration of 9,787 p.p.m. and other salts, including magnesium chloride, calcium carbonate, and magnesium carbonate, in quantities sufficient to bring the total salt content to the concentration mentioned. Despite the fact that this was the sole source of drinking water for these sick birds, and that they were given practically no individual attention, 54 percent recovered.

It would seem, therefore, that the postulate of alkali toxicity if applied to the Tule Lake basin must rest on the assumption that the birds were locating saline pools of a concentration greater than any revealed by this investigation, or else were obtaining toxic alkali at other points in the Klamath Falls district where such concentrates existed. Field observations on the birds themselves indicated the ducks did not habitually leave the Tule Lake basin during August and September, since within it were all the essentials for existence—water, food in the surrounding grainfields, and shelter and protection on the Federal bird refuge. However, at the Government sump, an irrigation basin south of Klamath Falls, solutions of salines far above the minimum lethal concentration were to be found in pools about the border. Under such conditions, which are comparable with those existing at many other of the more highly saline duck-sickness areas of the West, it is possible for waterfowl to come in contact with lethal quantities of toxic salts throughout the summer and early fall. Yet at the same time and place the relatively fresh water (3,000 p.p.m.) of the main sump supported a luxuriant stand of *Potamogeton pectinatus*, which served as a constant attraction to the waterfowl. If the theory of alkali intoxication is entertained under such conditions, it must be predicated upon the assumption that sufficient

toxic salines are ingested by birds on visits to the shore line, despite the fact that most of their feeding and drinking take place in the essentially wholesome water of the open sump.

Another consideration of paramount importance, but usually overlooked in attempts to explain duck sickness on the basis of alkali toxicity, is the reaction of birds to the taste of toxic saline concentrations. In every duck-sickness area visited there have been, within a short flying distance from any toxic alkaline pools that may have existed, ample supplies of suitable drinking water. At times the distance from one to the other was a matter of only a few yards, and if the birds possessed any marked aversion to the toxic waters it would be difficult under such circumstances to conceive of thousands ingesting lethal doses.

Mention has been made of the refusal of ducks to drink exceedingly high saline concentrations (80,000 and 200,000 p.p.m.), in experiments conducted in this study (p. 18). Others also have noted this fact. It remained to be demonstrated, however, whether concentrations of about minimum lethal strength would be refused by birds having equal access to wholesome water. An experiment was undertaken therefore, with a solution of natural alkali, composed mainly of sulphates, prepared in a strength of about 20,000 p.p.m. By trial this was found to be nontoxic to ducks using it as drinking water for a period of a week. When this was offered along with equally accessible fresh water, a marked aversion to the saline solution was revealed.

From the foregoing it may be stated (1) that solutions containing dissolved alkali of the Klamath Falls district in concentrations as great as 26,000 p.p.m. have been shown to be lethal to ducks when used as the sole source of drinking water; (2) that although such concentrations may be found in pools in the vicinity of certain duck-sickness areas, extensive outbreaks have occurred without their presence; and (3) that waterfowl have shown a sense of discrimination, even against nontoxic solutions of salts, that in all probability would lead them to shun toxic concentrations when fresh or relatively fresh water is close at hand.

### LACK OF SYNCHRONISM BETWEEN DUCK SICKNESS AND SEASONAL FLUCTUATIONS IN ALKALI CONCENTRATION

Other factors being equal, it might be assumed, on the basis of the theory of alkali toxicity, that duck sickness would have a seasonal incidence conforming to the period of high concentrations of alkali. In general this is true, but a day-by-day study of conditions of alkalinity, before, during, and after an outbreak of the disease, fails to demonstrate a real synchrony between duck sickness and high concentrations of alkali.

The outbreak of duck sickness that occurred on overflowed land at the northeast corner of Tule Lake in 1929 began under a condition of slowly rising water, which had existed for some time previously. The gradually extending sheet of water was absorbing encrusted alkali, and as it crept forward it formed areas of relatively high saline water, although not in concentrations that could be considered toxic (p. 18). This process had started about the first of July and continued steadily until well into October. In the course of that

process sickness appeared about August 1 and disappeared about September 20.

The failure of duck sickness to appear at the same point when essentially similar saline conditions are re-created in different years was brought out in the course of field work at the Largent Pond, previously mentioned. Prior to 1928 the pond evaporated to dryness during summer, but in that year it was kept full throughout the season by a break in a nearby irrigation ditch. Duck sickness appeared and caused the death of almost an entire flock of domestic ducks frequenting the area. In 1929 the break in the dike was repaired and again the pond evaporated to dryness with no sickness in evidence. In 1930 this area was used as a site for experimental work. The depression was flooded and a constant water level was maintained, approximating that prevailing in 1928 when sickness occurred. Alkali conditions also appeared to be similar. Despite the fact that alkali toxicity was demonstrated with birds confined in pens on the shore line of this pond (p. 17), and notwithstanding the presence of both domestic and wild birds on the pond throughout the season, true duck sickness did not appear.

Besides these and many other instances of lack of direct synchrony between duck sickness and high concentrations of saline solutions it has been Kalmbach's frequent observation, while engaged in recording water levels, alkalinity, and other factors having a possible bearing on the cause of the disease, that the seasonal increase in alkalinity is gradual. Duck sickness, on the other hand, may become a pronounced epizootic almost spontaneously. With the termination of seasonal outbreaks, however, a decrease in alkalinity may, with sounder logic, be interpreted as an influencing factor, since the disease invariably subsides with the coming of fall rains or with a pronounced increase in water depths, either of which would tend to dilute saline waters.

### SYMPTOMS OF ALKALI POISONING AND DUCK SICKNESS COMPARED

Differences noted between the clinical as well as post-mortem aspects of cases of duck sickness and of alkali poisoning, experimentally produced, have aided in distinguishing the two maladies. Not a single typical case of either acute or chronic duck sickness was produced in more than 50 individual experiments involving the administration of alkali or alkali solutions. In this connection mention again may be made of the toxicological studies of Shaw, who stated in his final published contribution on the subject that, although he felt that some symptoms comparable to those of duck sickness had resulted from the feeding of alkali, he "was not satisfied that the identical picture of the disease has been reproduced" (*62, p. 567*).

In view of their negative nature merely a summary of these experiments will be presented. They may be divided into two groups: One of 17, in which the salts were conveyed in solution either as drinking water or as doses administered through a pipette; and another of 34, in which dry salts, enclosed in capsules, were force-fed. The major portion of the solutions offered as drinking water were made from encrusted alkali found in the Klamath Falls district, and whenever the quantity of dissolved salts approached or exceeded 30,000 parts per million, fatal results ensued. In the feeding of dry

salts, including quantities of natural alkali, only one bird (affected by complications of unknown character) died. In these experiments many synthetic combinations of alkali also were prepared, including the local dominant salts as well as those suspected at Great Salt Lake. Both calcium chloride and magnesium chloride, singly and in combination with each other and with other salts, were fed in doses of 6 to 8 g without ill effects. Single doses of similar size were given, involving natural and synthetic alkali to which were added quantities of nitrates, with a view to increasing the toxicity. In none of these were symptoms characteristic of duck sickness produced.

In comparing the syndrome of alkali intoxication and duck sickness, one is confronted, on the one hand, with variations in the character of alkali as found in nature and, on the other, with differences arising from the severity of the attack in duck sickness, which may vary from a slight impairment of gait or flight to a condition of complete prostration. That certain physiological reactions arising from each are so similar as to be easily misinterpreted adds to the difficulties of comparison. The following presentation of analogous reactions sets forth some of the more obvious symptomatic and pathological differences and similarities of alkali poisoning and duck sickness as observed in this study:

| *Alkali poisoning* | *Duck sickness* |
|---|---|
| 1. A general depression occurs in lethal cases, which at times takes on the aspects of a paralysis. The power of sustained flight is lost; the legs become weak, and an unsteady or stumbling gait results; eventually the victim can no longer stand, whereupon death follows, often spontaneously. | 1. A paralytic condition, affecting in turn the muscles of wings, legs, and neck, is characteristic, but except in extremely acute cases death follows a gradually increasing lethargy. Complete prostration is typical for a variable period previous to death, which usually takes place without struggle. |
| 2. Respiration may be weakened and its rapidity slackened (a condition appearing immediately prior to death), but there is no well-defined air hunger during the middle stage of disability. | 2. The progressive paralysis affects muscles controlling pulmonary movements. This manifests itself as an air hunger, giving rise to a gasping effort at every breath. It is a frequent and fairly early symptom in most birds affected, and is particularly pronounced in gulls. |
| 3. With the increasing impairment of voluntary and involuntary faculties the nictitating membrane of the eye is sometimes affected. This usually results simply in a slowing up of its functions but at times the membrane may become immobile. The winking of the eye may be a slow, complete, but infrequent process. | 3. Paralysis of the nictitating membrane is a frequent but not a pathognomonic symptom. Unlike its occurrence in alkali poisoning, it is not confined to the final stages. In lethal cases it appears early; in sublethal cases it usually synchronizes with the peak of the syndrome, or may even be absent entirely. A much more constant accompaniment of duck sickness than of alkali poisoning. |
| 4. Fluid discharges from the nostrils as well as from the eyes have been noted in experimental birds subjected to alkali treatment, but in no instance have the discharges observed been of a character or in profusion sufficient to clog the glottis or seal the eyelids. | 4. Profuse discharges from eyes and nostrils are frequent and may thicken into cheesy masses that clog the glottis, block the trachea, or harden and seal the eyelids. According to Wetmore much of this has its origin in enlarged Harderian glands at the anterior corner of the eyes. |

| *Alkali poisoning* | *Duck sickness* |
|---|---|
| 5. A diarrhea is frequent, a natural result of the purgative effect of the salt ingested. | 5. A greenish diarrhea is common, terminating with the discharge of increasing quantities of white renal matter, the subsequent hardening of which may completely obstruct the vent, with a resultant distention of the cloaca. |
| 6. A lowered body temperature with a weakened, less rapid, or irregular heart action is common in the later stages. | 6. A subnormal body temperature is likewise characteristic. Even in sublethal cases a temperature of less than 100° F. has been noted in ducks. |
| 7. The alimentary tract almost invariably reveals evidence of severe irritation. There have been observed profuse mucous discharges from the esophagus and the glandular portion of the proventriculus, a sloughing of the edges of the gizzard lining, and a quite constant congestion of the blood vessels of the intestine, particularly those of the duodenal loop. | 7. Post-mortem examinations in the Klamath area showed no gross lesions in the intestinal tract comparable with those arising from the irritant action of salts. Occasional congestion of the blood vessels, a hardening and contraction of the walls of the smaller intestine, straw-colored contents, and a distention of the cloaca anterior to an obstructed vent are the only post-mortem manifestations that occur with any degree of frequency in the intestines. |

Of the distinguishable differences thus revealed in the syndromes and post-mortem conditions of alkali intoxication and duck sickness, those outstanding are the spontaneity of death and the presence of very evident lesions, in alkali intoxication; and, in duck sickness, the presence of an air hunger, the frequent paralysis of the nictitating membrane, and the lack of pronounced lesions. There are other more or less subtle and less clearly defined points of difference which, though they cannot be described adequately or appraised, can be detected by the experimenter and field observer after many contacts.

In summarizing the subject of alkali toxicity and its possible relationship to duck sickness it may be pointed out (1) that appraisal of the chemical composition of waters in sickness and nonsickness areas about Klamath Falls has yielded little to strengthen the alkali theory; (2) that, although concentrations of dissolved salts as low as 26,000 p.p.m. are lethal when such solutions are used as the sole source of drinking water, pronounced outbreaks of duck sickness have occurred in areas where such lethal concentrations did not exist; (3) that healthy experimental birds have shown an aversion even to nontoxic or mildly toxic concentrations of salts, and hence would be inclined to avoid highly toxic solutions where fresh water is equally available; (4) that there often is a lack of synchrony between the incidence of duck sickness and the seasonal period of high alkaline concentrations; and lastly, (5) that there are marked differences in the symptomatology and pathology of the two ailments.

## OTHER STUDIES

The earliest contact of the Biological Survey with the investigative aspects of duck sickness occurred in May 1911, when Kalmbach, in company with officials of the New State Gun Club, inspected the area at the mouth of the Jordan River, Utah. Evidences of the great mortality of the previous year were still present in the many hundreds of disintegrated bodies of ducks and shore birds. The first

signs of the season's outbreak of duck sickness also were then appearing, a few affected birds being encountered. Two of these, a shoveler and a widgeon, were transported to the laboratory of the Bureau of Entomology, at Murray, Utah, where, placed in a bath tub, both recovered after 4 days and were released.

In August 1913, S. E. Piper, of the Biological Survey, made an examination of conditions at Great Salt Lake; and in the same year Frank C. Clarke, detailed by the California Fish and Game Commission and working in cooperation with the University of California, made an investigation and conducted experimental work at Tulare Lake, Kings County; and Buena Vista Lake, Kern County, Calif. (*7*) A report on Clarke's early work (*8*) indicated, as was noted at Great Salt Lake, that a high percentage of the afflicted birds recovered when placed in cages containing fresh water, but no definite causative factor was demonstrated.

In July 1914, Wetmore began an investigation that continued through the two following seasons. In the first year he made field studies at a number of points about Great Salt Lake, particularly in the marshes at the mouths of the Jordan, Weber, and Bear Rivers. Late in the season he visited Tulare and Owens Lakes. At the conclusion of the first year's work he prepared a preliminary report, which was published in May 1915 (*70*). This covered such aspects of the problem as its history and the theories as to cause and nature of the trouble, and led to the conclusion that the mortality was due to an alkaline poison, the exact nature of which still remained to be determined.

In 1915, he continued his studies and, as an aid, established a small field laboratory on the banks of the Bear River at the northern end of Great Salt Lake. Operations were continued there until the end of October with the exception of a short period of investigation at Lake Bowdoin near Malta, Mont., where an outbreak of duck sickness had occurred earlier in the season.

In 1916, the last year of Wetmore's studies at Great Salt Lake, field work began on May 15 and terminated on October 25. The final conclusions coincided with those published in the preliminary report (*70*), though certain salts of alkali, particularly the chlorides of calcium and magnesium, were then definitely incriminated. The report on the entire study at Great Salt Lake was published on June 21, 1918 (*71*).

After the publication of Wetmore's findings no further extensive research work in duck sickness was undertaken for nearly a decade. Although articles of a nontechnical character appeared from time to time in periodicals devoted to wild life, it was not until 1927 that the malady was again given serious study. Early in that year E. W. Nelson, then Chief of the Biological Survey, published the results of a general field survey of conditions existing in 1926 (*52*).

In that same year the California Fish and Game Commission in cooperation with the University of California undertook further study of duck sickness. Toxicological and pathological studies were conducted at the laboratories of the Hooper Foundation for Medical Research, with K. F. Meyer, director of the foundation, supervising. At the same time parasitological studies were conducted in the Zoological Department of the University of California, under the di-

rection of C. A. Kofoid (*44*). At the outset R. J. Irvine carried out chemical research, but later the purely toxicological and pharmacological aspects of the problem were handled by Paul A. Shaw, of the Hooper Foundation, who published several papers (*59*, *60*, *61*, *62*). Parasitological studies were started in November 1927, by O'Roke (*53*), who published his results in the following year. Pathological investigations were begun in June 1928 by Van Roekel, and a brief paper outlining his field of endeavor appeared in January 1929 (*69*), but at that time no additional light was shed on the nature of the malady. Field work connected with these studies was conducted at Tule Lake, and at points in the San Joaquin Valley.

In a review of the literature on duck sickness, mention should be made of three more recent contributions by M. Hobmaier, (*38*, *39*, *40*), who joined the staff of the Hooper Foundation for Medical Research in September 1930. In the following month Kalmbach had opportunity to reveal to Dr. Hobmaier the progress made at the field laboratory at Klamath Falls, accompany him on his initial inspection of the Tule Lake district of infection, and present him with culture material, from which he later isolated *Clostridium botulinum*, type C, thereby corroborating the earlier findings of Giltner and Couch (*25*, *p. 660*).

In his last contribution to the subject Hobmaier (*40*) presented a mass of significant and valuable data and adequately demonstrated duck sickness to be botulism by (1) the similarity of epidemiology and clinical picture, (2) the isolation of the causative organism, and (3) the demonstration of toxin in media in the field, as well as (4) in the blood stream of afflicted birds.

More recently the contribution of Gunnison and Coleman (*29*) to the fundamental bacteriology of the duck-sickness variant of type C botulism has appeared and supplied research workers with important descriptive facts not previously determined for this type.

## HISTORY OF THE MORTALITY[8]

It is of importance in the consideration of a malady now looked upon as an outstanding menace to western waterfowl to note its history. Has this disease always been a factor in curbing the number of North American waterfowl, or is it a disaster of recent origin? If evidence points to its presence in early days, have the consequences always been as severe as they are in current times, when the mortality in some seasons is appalling? These are questions the answers to which not only have a direct bearing on a proper understanding of the problem as it is presented today but also are of importance in any attempted appraisal of what the future may have in store.[9]

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[8] The historical aspects of duck sickness here discussed concern the manifestation of this disease among wild birds; no attempt is made at this point to deal with the same or related maladies among domestic poultry or livestock. In the presentation of data concerning the history of duck sickness about Great Salt Lake, use has been made of the evidence compiled by Wetmore (*71*), to whom acknowledgment is gratefully made.

[9] The evidence on which early accounts of the malady are correlated with our present concept of duck sickness rests largely on the basis of similarity of symptoms and certain associated etiological factors. In a few of the localities in which the disease had been recorded, recent bacteriological determinations, by demonstrating the presence of the causative organism, have strengthened the supposition that early outbreaks were identical with those of today. There is always the likelihood, however, that other factors, including even direct toxicity of alkali, might have played a part in some of the early outbreaks. Consequently, no records about which there is a reasonable doubt are here included or, if mentioned, they are presented with appropriate explanation.

### PERIOD PRIOR TO 1910

In discussing conditions at Great Salt Lake with respect to early records of the malady, Wetmore stated that—

> several hunters and guides who have shot on these marshes for many hunting seasons have recalled that sick and dead birds were found at an early day. Twenty-five years ago [1893] the hunting season began on September 1, and . . . It was not unusual to find many dead ducks on this date . . . Some of the early settlers in this region have reported sick birds at earlier times (*71, p. 2*).

A. K. Fisher, of the Biological Survey, reported finding many dead eared grebes and shovelers at Owens Lake in June 1891 under conditions that led him to believe their death may have been caused either by toxic alkaline salts, which were present in high concentrations, or by futile efforts to find suitable food in the highly saline water (*21, p. 12–13*). Nelson also reported large numbers of dead grebes in an exceedingly emaciated condition on the same body of water in December 1890 (*21, p. 13.*) A still earlier reference to bird mortality at Owens Lake, by Loew (*43, p. 190*), is to be found in Wheeler's report of 1876 on western geographical surveys, in which the statement is made that—

> notwithstanding the alkalinity of Owens Lake, numerous ducks are occasionally seen swimming on it. The great numbers of dead ducks and other aquatic birds seen here and there on shore seem to indicate that they tried to satisfy their thirst with this water.

In 1914 Wetmore visited Owens Lake, found many dead eared grebes and a few other birds, and stated, "apparently the cause of death was similar to that producing the duck sickness in Utah" (*71, p. 5*). In the absence, however, of definite bacteriological evidence of duck sickness at Owens Lake the record of its occurrence there is open to question. Several factors contribute to this element of doubt. One is that excessive mortality from this disease seldom occurs as early as June, the time of Fisher's observations; another, that general emaciation, as reported by Nelson, is not a common pathological condition in avian botulism; and, lastly, the high concentration of sodium carbonate in the waters of Owens Lake in all probability would make conditions highly unfavorable if not impossible for toxin production by the causative organism of duck sickness (p. 65).

Much of the literature of early exploring expeditions in the West has been searched with the hope of finding records of bird mortality that might be indicative of duck sickness. Among these records were the reports of military, engineering, and railroad survey parties and of geological explorations, and the writings of ornithologists who accompanied these expeditions. Ridgway (*55*) and Henshaw (*35*), both ornithologists, visited Great Salt Lake, the former in 1869 and the latter a few years after, but neither made comment on any extensive bird mortality.

Previously various expeditions had traversed the Great Basin and visited the shores of Great Salt Lake or the valley of Bear River to the north. These included the Ashley-Smith Explorations (1822–29), those of B. L. E. Bonneville (1833), and R. B. Sage (early forties), J. C. Frémont (1843), Howard Stansbury (1849–50), J. H. Simpson (1859), and others. These early explorers, all keen ob-

servers of wild life, made frequent mention of the abundance of birds, yet so far as the present reviewer can discern, no mention is made by any of an avian mortality that might be construed as an epizootic of duck sickness. During September 1843 Frémont (*22*) explored the Bear River Marshes and on September 9 traveled down the Weber River in a rubber boat, passed through the marshes at its mouth, and visited one of the islands in Great Salt Lake. From the standpoint of locality and time of year the opportunity of his noting duck sickness, had it been present during that season, was most favorable. Stansbury (*64*) explored the entire boundary of Great Salt Lake and also visited the Bear River and Weber River sections, yet he makes no mention of dead birds.

There are a number of later reports (previous, however, to 1880) concerning the central valleys of California, but in none was found reference to excessive bird mortality. Derby's Report of the Tulare Valley, 1852 (*12*), fails to mention any bird malady in a district in which endless thousands died in later years. In more recent times, what appears to be further negative evidence of duck sickness is found in reports of the Agricultural Experiment Station of the University of California covering the period from 1879 to 1889.

Particularly interesting is the recorded history of variations in the levels and alkalinity of the waters of the upper San Joaquin Valley with relation to animal life. Although the subject was studied primarily from an agricultural standpoint, Hilgard (*37*) in 1889 took note of the progressive destruction of mollusks and fish. He gave attention to the decrease in the fishing industry in the Kern and Tulare Basins in the 1879–89 decade, but despite close observation of wild life during that period, he noted no bird mortality. Wetmore stated that sick ducks had been observed in the Tulare Lake Basin for more than 20 years, which, it appears, would place the incipience of duck sickness as an epizootic there at some point in the nineties (*71, p. 5*). This antedates by 10 or more years the origin of the trouble in that vicinity as reported by the California Fish and Game Commission (*7*), which considered the year 1908 or 1907 as the first year of noticeable mortality.

Only one of the numerous outbreaks of suspected duck sickness of which there is record, reported from localities other than the vicinity of Great Salt Lake or the San Joaquin Valley, Calif., occurred prior to 1910. This one, of somewhat doubtful identity, appeared among geese at Bitter Lake, 25 miles northwest of Watertown, S.Dak., late in the fall of 1898.

It would seem, therefore, from the review of pertinent literature, that the earliest records of true duck sickness that may be pointed to with reasonable assurance are those mentioned by Wetmore for the early nineties at Great Salt Lake (*71, p. 2*).

#### PERIOD 1910–19

Waterfowl mortality in 1910 served for the first time to call national attention to the menace of duck sickness. It appeared at a number of points, but the outbreak at Great Salt Lake during that season was the most severe in any single area of infection. Waterfowl and shore birds died in such numbers that private clubs refused to open their grounds to hunting. In California during the

same season thousands of birds died in the Soleta, Goose, Buena Vista, and Tulare Lake sections of Kern and Kings Counties, in waters that are no longer existent, and from Saskatchewan, Canada, came reports of the death of "untold thousands" in the vicinity of El Fros, about 100 miles north of the United States. A short time later (1912–13) what appears to have been duck sickness was reported from the vicinity of Rice and Goose Lakes, west and southwest of Saskatoon. This locality still remains, so far as known, the most northerly for duck sickness on the North American Continent, a point fully 200 miles north of the Canadian border, at 52° north latitude.

In fluctuating but generally in decreasing intensity, duck sickness continued to take a toll throughout the decade 1910–1919. The year 1913 was one of considerable mortality in the upper San Joaquin Valley, and from Saskatchewan in the same year there came reports of renewed trouble near El Fros. At Great Salt Lake the year 1911 witnessed an improvement over the disastrous conditions of 1910 but in 1912 and 1913 excessive mortality again occurred. Conditions in 1914, when the Biological Survey began its initial study of duck sickness in Utah, were the best there since 1910. In 1915 extremely low water drove most of the waterfowl out of the infected area about the lake, with a resultant saving of many; but in the following season, after a return to nearly normal water conditions, duck sickness recurred in moderate intensity. During the remainder of the decade (1917–19) the disease occurred each year, but the losses were relatively small.

In 1915 Wetmore observed the disease at Lake Bowdoin, near Malta, Mont.; he also reported it in 1916 and 1917 at Baca Lake, 35 miles south of Lake Malheur, Oreg. (*71, p. 5–6*). Stanley G. Jewett and W. L. Finley observed duck sickness for the first time at Lake Malheur itself in 1917, and in the following year a few birds, afflicted apparently with duck sickness, were found in the vicinity of Lower Klamath Lake on the Oregon-California line while this body of water was evaporating to dryness. Burnie Maurek, game and fish commissioner of North Dakota, reported sick ducks at an alkaline lake in southeastern Kidder County, about 1915. In 1917 duck sickness was reported from the Salton Sea in southern California. A moderate outbreak occurred among the ducks in the Marysville Butte section of the Sacramento Valley, Calif., in 1918, and soon after there was added to the list of localities Dodson Lake, in the Warner Valley of south-central Oregon. During the latter half of this decade (1915–19) duck sickness, though appearing in localities not previously reported, nowhere assumed the serious proportions it had attained at Great Salt Lake and in the San Joaquin Valley in preceding years.

### PERIOD 1920–32

Since 1920 the history of duck sickness has been characterized by a notable increase in the number of points of outbreak. Although part of this apparent spread results from the closer attention being paid to the welfare of wild life and the fact that duck sickness has become a matter of more common knowledge among sportsmen, it is evident that the disease appears today in epizootic intensity in many more localities than in 1920. It is still present, though in

fluctuating intensity, at most of the earlier recorded localities. At Great Salt Lake the year 1921 witnessed the greatest mortality since the outbreak of 1910; a decrease followed during subsequent years, and in 1924 additional improvement resulted through energetic frightening measures employed in driving the birds out of infected areas. Moderate mortality occurred in following years until in 1929, when, in August, there was a short-lived but severe outbreak at the mouth of Bear River. Frightening measures applied during the summer of 1930 curtailed what might have resulted in an epizootic of considerable extent, and in 1931, the disease was extremely localized. In 1932, however, the malady reappeared in its most violent form about the Bear River Bay, and on the south shore of Willard Spur the dead lay in numbers that recalled the catastrophe of 1910 about Great Salt Lake (p. 26).

What appears to have been true duck sickness among waterfowl on Utah Lake, 50 miles south of Great Salt Lake, was reported by Clarence Cottam, of the Biological Survey, as occurring in 1927 and 1928. Reports current at the time were that the disease had been noted several years previously.

In the upper San Joaquin Valley duck sickness was prevalent in varying intensity throughout the period, but on the whole the mortality was much less than during the previous decade. New spots of infection appeared, however, under peculiar etiological conditions on the artificially flooded and baited grounds of certain duck clubs. In 1927 there was great mortality in the vicinity of Buena Vista Lake, and in 1931 there was an outbreak of considerable intensity on the south shore of the Salton Sea at a point where the inflowing waters of the New and Alamo Rivers formed mud flats. In that year a few ducks died on the grounds of hunting clubs in the vicinity of Colusa, in the Sacramento Valley, under conditions strongly suggestive of duck sickness.

Early in this period the bed of Tule Lake was added to the list of known infected areas, later the scene of much of the field work of the present study. Although many waterfowl perished there during the first year that attention was attracted to the malady (1922), severe mortality occurred in 1925 and, to a less extent, in 1926[10]. The disease was not prevalent at Tule Lake in 1927, but there was an outbreak of moderate intensity in the fall of 1928 and localized outbreaks in each of the three following years.

In Oregon, duck sickness appeared in its most disastrous form at Lake Malheur in Harney County in 1925, a year of low water. It recurred in reduced intensity the following season; reached serious proportions again in 1929; and in 1930 and 1931 was absent, owing to the drying of the lake bed. The initial recorded outbreaks on bodies of water in parts of southern Oregon contiguous to the Tule Lake district of California appeared subsequent to 1925. These areas included marshes at the north end of Upper Klamath Lake, the Keno Marshes along Klamath River, and what is known as the Government sump, an irrigation catch-basin 10 miles south of Klamath Falls.

In Idaho the earliest recorded instance of duck sickness is that of an outbreak at Mud Lake, Jefferson County, in 1922, in the course

[10] TONKIN, G. REPORT ON DUCK SICKNESS AT TULE LAKE, CALIF., KLAMATH LAKES, OREG., AND ADJACENT TERRITORY. 1926. (Manuscript in files of Bureau of Biological Survey.)

of which both wild and domestic ducks were affected. In 1929 mortality was again reported from the same general vicinity (Hamer). What appears to have been duck sickness has been noted at Bear Lake and the area just north of the Utah line (1926 and 1929) and at the American Falls Reservoir, Power County, where many birds died under essentially fresh water conditions in 1928. All these localities lie directly north of Great Salt Lake.

Lake Bowdoin, Phillips County, Mont., the scene of an outbreak reported by Wetmore (*71, p. 5–6*), again was the source of sick birds in 1921. George E. Mushbach, of the Biological Survey, encountered thousands of dead bodies there early in October of that year, evidence indicating a severe outbreak a little earlier in the season. What may have been duck sickness has been reported by Carey H. Bennett, of the Biological Survey, in recent years at Benton Lake, Cascade County; and Greenfield Lake, Teton County (not charted in fig. 1).

In Nevada there are two records to be considered in connection with the distribution of duck sickness. One of these emanates from the southeastern part of the State, where in the summer of 1930 several hundred birds died at Frenchmans Lake in the Pahranagat Valley, Lincoln County, under conditions that strongly suggested duck sickness. In the same season numerous avocets died on shallow alkaline lakes east of Fallon in the west-central part of the State. The evidence of duck sickness in this case, however, is not so clear.

Although the disease may have manifested itself at earlier dates in North Dakota, there is no question that it has been increasing in frequency during recent years. The center of the reported infection has been in the highly alkaline southern parts of Burleigh and Kidder Counties. In August 1929, F. M. Uhler, of the Biological Survey, noted two duck-sickness areas, one in Graf Township in southeastern Kidder County, and the other at Long Lake in the southwestern part of that county. At the latter point domestic chickens and turkeys also succumbed. In the following year large numbers of wild fowl died at Chase Lake Bird Refuge, in northern Kidder County, according to the report of Protector W. D. Parker. Earlier mortality at Cranberry Lake (1927) may not have been due to duck sickness but to the direct toxicity of alkaline salts, which were present in concentrations great enough to form dense crystaline deposits on the plumage of affected birds.

In South Dakota the history of duck sickness is recent, with the exception of the doubtful case occurring near Watertown in 1898 (p. 26). The first definite outbreak of which there is record was that reported by F. C. Lincoln, of the Biological Survey, at White Lake, Aurora County, in 1922. In 1927 the disease was reported from Rush Lake, near Webster, Day County, where it was learned the malady was of annual occurrence. Another Rush Lake, in Hamline County, was the scene of duck sickness in 1929, as was also Lake Poinsett nearby. No less than 20 species of birds, including a ring-necked pheasant, were found dead about this lake by Uhler in September, and he also encountered duck sickness at Lake Mitchell in Brookings County in the same year. From Antelope Lake, Clark County, there were received, in December 1930, specimens of mallards that evidently had died of lead poisoning, but the internal organs, after suitable incubation, yielded *Clostridium botulinum*, type C,

which indicated that the organism of duck sickness was present in that vicinity also.

In October 1931 Gunderson visited Oaks and Sylvan Lakes in Cottonwood County, Minn., and there found evidence of what appeared to have been an outbreak of typical duck sickness that had its peak at some time in August or September (*27*). Wild ducks, shore birds, and domestic poultry died in great numbers on the mud flats surrounding these lakes, and cultures made from material collected there revealed the presence of the organism. This is the most eastwardly record in the United States of duck sickness in epizootic form among wild birds in the region of alkaline water.

In Nebraska, duck sickness has been recorded at points in the sand hills of Garden and Sheridan Counties within this period, even as recently as 1932. In that year the disease was reported at Gay Lake, near Irwin, Cherry County; and at Whitney Lake, Dawes County.

In the Cheyenne Bottoms, Barton County, Kans., there appears to have been a similar malady in the fall of 1926. A much earlier report of mortality recorded by Wetmore (*71*, *p. 6*) as having occurred in this locality in 1914 and 1915 was at that time diagnosed at the University of Kansas as a bacterial infection.

In the Panhandle of Texas duck mortality came rather suddenly to the attention of sportsmen within recent years, although observers familiar with conditions contend that the malady has been an annual occurrence there over a longer period. It was reported as severe in the vicinity of Amarillo, Potter County, in 1926 and 1927, and prevalent at other points in western Texas during these years. In 1930 an intense but local outbreak appeared about small bodies of water near Cone, Crosby County. Desiccated specimens collected at these points in the year following afforded circumstantial evidence of the identity of the malady by the disclosure of the organism of type C botulism.

Waterfowl mortality in an overflowed area adjacent to the Rio Grande at San Acacia, N.Mex., (1927) resulted in the death of a few birds; as also at the Picacho Reservoir, Pinal County, Ariz., in October 1928. Although definite evidence is lacking, the circumstances suggest duck sickness.

A case of possible duck sickness was revealed at a point east of the Mississippi River when, on December 14, 1930, a single black duck was captured in a helpless condition near Dyke, Va., by W. H. Ball and H. S. Barber. Subsequent observation of the bird in captivity revealed a partial (probably residual) paralysis of some of the major muscles. After 2 days in captivity the bird was killed and its liver removed under sterile conditions. From this, Giltner recovered *Clostridium botulinum*, type C. Though there is the possibility that the liver contamination had its origin from bacteria adventitiously ingested, and was in no way connected with the bird's ailment, the symptoms were suggestive. The case serves at least as a definite locality record for the organism.

Mention may be made of the sickness and death of shore birds reported in September 1930 in Massachusetts Bay, where they were feeding in the vicinity of carcasses of blackfish (*Globicephala melaena*), which had been washed onto the beach and were undergoing

decay (*1*). Turnstones and sanderlings, feeding on the adult and possibly larval and pupal blowflies (*Calliphora*) infesting the carcasses, became afflicted with a paralysis of the major muscles and showed other symptoms of typical duck sickness. Although no bacterial evidence of the identity of this malady was obtained at the time, the circumstances surrounding the outbreak and the symptoms displayed point to botulism of some type. Incidents such as this, which are the direct result of a single local spot of infection, closely typify the conditions under which domestic poultry contract botulism and are not to be classed with the extensive epizootics among wild birds in the West.

Outside the borders of the United States, duck sickness has appeared in its most virulent and disastrous form in recent years in the southern portions of the Canadian Provinces of Saskatchewan and Alberta, directly north of Montana. Early in this period (1920 and 1921) a malady reported by Munro (*51, p. 83*) occurred among waterfowl at Lake Johnstone, Moose Jaw County, Saskatchewan, and was diagnosed at the time as coccidiosis and as septicemia. The symptoms, however, were similar to those exhibited by sick birds at Lake Newell (next mentioned) and in a present-day review of the evidence, duck sickness seems the logical diagnosis.

What appears to have been true duck sickness occurred for the first time at Lake Newell, Bow Valley County, Alberta, in 1924, and in the following year an epizootic of considerable severity ran its course in the same locality. The excellent and well-illustrated account of this outbreak by Munro leaves little doubt concerning the nature of the trouble (*51*). In 1926 no sickness was observed, and apparently it did not recur until 1930 when, according to A. Griffin, of Brooks, Alberta, a number of dead ducks were reported despite the fact that much fresh water had flowed into Lake Newell that season.

In Saskatchewan duck sickness was reported again (1927) at the point of its most northerly occurrence west of Saskatoon, and in 1928 there was some mortality at Lucky (Luck) Lake in Elrose County. In the following season, however, a malady in all its superficial aspects similar to duck sickness, made heavy inroads on the waterfowl of both southern Alberta and southern Saskatchewan. In that year many thousands died on the shores of Pakowki Lake, Medicine Hat County, Alberta, just north of the Montana border. At Many Island Lake, Redcliff County, Alberta, ducks died in July and August, it was stated, from the effect of leeches (p. 11), while at Cypress Lake, near Vidora, Saskatchewan, a severe malady occurred, the cause of which was uncertain.

South of the Rio Grande there is record of a malady that may have been duck sickness occurring in the fall of 1925 in northeastern Durango. There, according to Nelson (*52, p. 92*), in a district known as Bolson de Mapimi, which extends into adjacent southwestern Coahuila, formerly existed the Laguna de Meyran, a body of water more than 30 miles in length, and numerous smaller lakes. Diversion of water for irrigation has reduced the flow into this basin, which now is devoted largely to agriculture. The remaining marsh areas and flooded fields, however, are still a great attraction to waterfowl. In one section, near the town of Tlahualilo, many thousands of birds,

especially pintails, blue-winged teal, and sand-hill cranes, died in 1925 under conditions that indicated duck sickness. E. A. Goldman encountered no sickness when visiting this area in March 1926, but found considerable evidence of the previous year's mortality in the form of disintegrating bodies.

Early in the past decade (1921) Wetmore, while studying migratory birds in South America, found evidence of a malady among wild fowl in the vicinity of Laguna Castillos, near San Vicente de Castillos, Uruguay, the symptoms of which were the same as those of the disease he had studied in the Salt Lake Valley. His manuscript notes in the files of the Biological Survey, under date of January 31, 1921, show that several species were affected, including the southern pintail, a coot, Trudeau's tern, the brown-headed gull, and the lapwing, or teru teru (p. 41).

## EXTENT OF DISTRIBUTION AND MORTALITY

The map (fig. 1) of the known distribution of duck sickness as an epizootic among wild birds in North America shows roughly a wide-flung circle having in its circumference points in the southern portions of the Canadian Provinces of Saskatchewan and Alberta, south-central Oregon, northern, central, and southern California, two areas in Nevada, possibly points in Arizona and New Mexico, and areas in the Panhandle of Texas, western Nebraska, eastern South Dakota, south-central North Dakota, and southwestern Minnesota. Near the center of this great circuit is Great Salt Lake, Utah, with infected areas of southern Idaho directly to the north. In the main this distribution, especially that part representative of the areas of greatest mortality, conforms roughly to the region of alkaline soils and waters of the United States. The significance of this correlation is discussed elsewhere (p. 63).

FIGURE 1.—Points from which duck sickness has been reported among wild birds. Bacteriological demonstration of botulism as the cause is limited to a very few of the localities, but the similarity of symptoms and significant environmental conditions have served as the basis of the records.

In the foregoing treatment by periods, duck sickness among wild birds has been traced with a fair degree of certainty as far back as the early nineties of the past century; its range now extends over an

enormous area. The history of events indicates an increase in prevalence; and from this comes the logical query as to whether a still further extension of range may be expected in the future.

That the causative organism of duck sickness, *Clostridium botulinum*, type C, is endemic in this continent and was here long before man recognized its presence through outbreaks of duck sickness, may be inferred from the studies of the same and other types of botulism investigated by bacteriologists. There is reason therefore to believe that duck sickness may have occurred at a very early time, whenever and wherever favorable etiological factors were present (pp. 61–68).

In looking backward, however, it is noted that man has altered greatly the extent and nature of conditions affecting duck sickness. Through reclamation, drainage, and deforestation there has resulted an increase in the rapidity and extent of seasonal run off of rainfall. Lakes and marsh lands that formerly maintained more or less constant water levels now fluctuate, and during late summer become stagnant areas of shallow water, mud flats, and decaying material. Alkaline sinks have been formed by drainage from irrigated sections. About many of these, grain crops have lured waterfowl in great numbers and have tended thereby to concentrate the birds in or near infected areas that formerly did not offer them much inducement to rest and feed. There is little doubt that there has been a material increase in the factors and general conditions conducive to duck sickness since civilized man has entered the picture; and, unless measures are taken to prevent a further extension of conditions favorable to the organism, the ravages of this disease are likely to make a still greater annual drain on our diminishing waterfowl.

Appraisals of the extent of mortality in severe epizootics were made as early as 1910 at Great Salt Lake, where sanitary conditions were being improved by gathering the dead bodies for burying or covering with lime. An idea of the intensity of the disaster may be had from the following description by Madsen (*45, p. 30–31*) of conditions about the lake in 1910:

> Our efforts were confined to gathering all the dead ones, loading them in flat-bottom boats with pitchforks, and hauling them to the nearest land to be piled up and buried or burned. . . . Three men with pitchforks accompanied each boat. I have seen many acres of water where these men could, within throwing distance, put in more than 200 birds without moving the boat. Small lakes would frequently yield more than 1,000 dead birds to the acre. We spent days at this work, until the utter uselessness of it all became apparent. The margins of the ponds and lakes soon became dotted with mounds of dead birds resembling rat dens in a marsh.

Wetmore has stated (*71, p. 3–4*) that in 1912—

> about 30,000 birds were picked up on the Weber River flats, while on Bear River, from records kept by V. F. Davis, it is learned that the bodies of 44,462 wild ducks were gathered and buried between August 22 and September 21.

Wetmore records in the following year that 46,723 ducks were buried between September 7 and September 26. He states further that "attempt was made to clean up only those birds lying in the open. These formed but a small part, so that the figures given probably represent less than 20 percent of the birds that actually died." Even in 1914, a year of considerable improvement over any of the preceding four, an estimate of 8,000 to 10,000 dead ducks was made

for a distance of 2 miles along one of the lower channels of the Weber River.

Others have attempted to appraise the extent of mortality by counting the number of dead and helpless birds on representative units and then computing the aggregate number on the basis of the total area affected. Such estimates may be subject to a great factor of error through inability to inspect much of the terrain, the tendency of bodies to be concentrated by wind and current action, and the habit of sick birds while still possessing powers of locomotion to hide in dense stands of marsh growth. Nelson (*52, p. 13*) states that on the Bear River Marshes, Madsen estimated the annual losses as from 30,000 to 100,000 or even more in years when the malady was particularly severe. There are seasons, however, when conditions of low water may result in the complete drying up of what are ordinarily duck-sickness areas, thus driving out the birds and preventing mortality. Such a condition prevailed in 1915, when Wetmore found sick birds scarce in some of the most severely infected areas of the Bear River Marshes. Estimates of dead ranging from less than 100,000 to more than 300,000 made at Great Salt Lake in August 1929, give a general idea of the severity of the epizootic in that year.

A rough estimate of the mortality at Lake Malheur in 1925, made by Steele, placed the number of dead at 100,000. At Tule Lake, Tonkin calculated the number of dead to be from 25,000 to 50,000 during the summer and fall of 1925. Early in the investigations of duck sickness in California an estimate of 40,000 dead waterfowl in one season (1913) was reported for the Buena Vista and Tulare Lake Basins (*8, p. 350*).

In the Klamath Falls–Tule Lake section of southern Oregon and northern California, nothing approaching the severity of outbreaks mentioned has appeared during the period of this investigation. In 1927 Sperry found no sick birds at Tule Lake, and only a few at other points in adjacent parts of southern Oregon. In the following year, 1928, an outbreak of moderate intensity ran its course late in the season. In 1929, 1930, and 1931 the mortality in the area was confined largely to overflowed land adjacent to Tule Lake, where it was estimated that about 1,000 birds died annually.

At the close of the severe, late-season outbreak at the north end of Great Salt Lake in 1932, an estimate was made of the number of dead on the south shore of Willard Spur. Sections of the shore line 100 yards in length were taken as units and the readily visible dead counted. For a distance of 6 to 8 miles dead ducks were scattered on the flat terrain in numbers ranging from 8,000 to 10,000 to the mile. (See pl. 1, *B*.) It was estimated that there were 150,000 dead on the south shore of Willard Spur and the adjacent Bear River Bay. Many more thousands lay scattered on the east, north, and west shores, and an indeterminate number were hidden in the vegetation of the Bear River Migratory Bird Refuge or obliterated on the mud flats. It was estimated that fully a quarter of a million waterfowl perished from duck sickness in this general area during 1932.

A limited to moderate mortality probably can be found in most of the principal infected areas every season. Epizootics of extreme

severity may be looked upon as the result of the combination of various etiological factors coupled with the attendant factor of an abundance of birds (*63*).

## SPECIES OF BIRDS AFFECTED

At the conclusion of his work in Utah, Wetmore listed 36 species of wild birds known to be susceptible to duck sickness. With all but one of these, the horned lark, he had had personal contact in the course of his studies on the Bear River marshes and elsewhere. It was Wetmore's experience (*71, pp. 11–12*) that the shallow-water, or river, ducks were more likely to contract the disease than others. The green-winged teal was considered to be particularly susceptible, followed closely by the pintail; while mallards, shovelers, and cinnamon teal succumbed less frequently. Of the deep-water ducks, the redhead was most often afflicted; and among shore birds, the avocets and black-necked stilts died in greater numbers.

In a tabulation of each species found dead at Tulare Lake in 1913, published by Clarke (*8, p. 220*), of 2,079 recorded, 642 were teals (presumably cinnamon and green-winged), 571 were pintails, and 540 shovelers. Sandpipers of several species aggregated 46, and other birds were found in smaller numbers. No mallards were recorded, a circumstance that can be interpreted only by the fact that few if any were in the vicinity of the lake at the time.

The record of mortality in southern Oregon and northern California in the period 1929–31 parallels in the main that noted by Clarke at Tulare Lake more than 15 years earlier. In point of numbers, pintails were the ducks most frequently affected, although a variation was noted between one season and another and at different periods during the same season. In 1931 there was a noticeable increase in the number of dead green-winged teal about August 20. Within a week, pintails again took the lead and died in greater numbers than had previously been noted in the same area. Sick shovelers frequently were encountered there and, by the low percentage of recovery revealed apparently a weak resistance.

The relative status of mallards, cinnamon teal, and redheads with respect to the disease about Tule Lake was closely similar to that described by Wetmore for these birds at Great Salt Lake; with shore birds, however, a marked difference was noted. Although in 1929 and 1930 avocets dominated the number succumbing at Tule Lake, in 1931 least and western sandpipers clearly took the lead. Mortality among gulls never was extensive at this lake, but at an irrigation basin south of Klamath Falls, juvenile ring-billed and California gulls supplied the first evidence of duck sickness in each of the three seasons devoted to the study. After this early-season mortality, gulls afflicted with duck sickness were found rather infrequently.

The accompanying annotated list of wild birds known to have contracted duck sickness under field conditions gives a more detailed picture of the mortality aspects of the outbreaks. Bacteriological proof of the identity of the malady that killed the birds of each species noted is, in most cases, lacking, the criterion for inclusion

being similarity of symptoms and certain associated etiological factors characteristic of outbreaks of true duck sickness. The species marked with an asterisk (*) were included in Wetmore's original list (*71, p. 12*). At present the number of species of North American wild birds known to have been affected by duck sickness totals 69, in 21 families.

*EARED GREBE. *Colymbus nigricollis californicus.*

A few dead were noted at Lake Malheur, Oreg., in September 1929.

*WESTERN GREBE. *Aechmophorus occidentalis.*

Found affected at Long Lake in southwestern Kidder County, N.Dak., by Uhler, in August 1929; at Lake Newell, Alberta, by Munro, in 1925; and at Lake Malheur, Oreg., by Kalmbach, in September 1929. Extensive mortality reported among these birds at Owens Lake, Calif., at an early date (1891) may not have been due to duck sickness (p. 25).

*WHITE PELICAN. *Pelecanus erythrorhynchos.*

FARALLON CORMORANT. *Phalacrocorax auritus albociliatus.*

Included on the basis of affected individuals recorded by Clarke, at Tulare Lake, Calif., in 1913 (*9, p. 220*). Occurrence of this outbreak at about the time the last of the fish in the lake perished, apparently from stagnant water conditions, may account for birds of this highly piscivorous species contracting the malady.

TREGANZA'S HERON. *Ardea herodias treganzai.*

Specimens of sick herons were encountered at Great Salt Lake by Lincoln in 1926, and in the Klamath Falls district by Sperry in 1927.

*SNOWY EGRET. *Egretta thula thula.*

BLACK-CROWNED NIGHT HERON. *Nycticorax nycticorax hoactli.*

Night herons, dying apparently from duck sickness, were observed at Long Lake, Kidder County, N.Dak., by Uhler in August 1929, and about Klamath Falls by Sperry in 1927.

*WHITE-FACED GLOSSY IBIS. *Plegadis guarauna.*

*CANADA GOOSE. *Branta canadensis canadensis.*

Reported affected also at Lake Newell, Alberta, by Munro in 1925 (*51*). A few succumbed about Tule Lake, Siskiyou County, Calif., in the course of this investigation.

WHITE-FRONTED GOOSE. *Anser albifrons albifrons.*

Birds of this species occasionally succumb to duck sickness about Tule Lake, but ordinarily they arrive from the north after the seasonal peak of the disease. Sick "speckle-bellies" were found there in 1926, 1927, and 1930.

*COMMON MALLARD. *Anas platyrhynchos platyrhynchos.*

Sick mallards have been found in all principal duck-sickness areas and from the earliest known outbreaks to the present.

COMMON BLACK DUCK. *Anas rubripes* subsp.

Included on the basis of a single specimen collected on the Potomac River below Washington, D.C., December 14, 1930. This bird manifested certain residual paralytic symptoms occasionally found in duck sickness and later *Clostridium botulinum*, type C, was isolated from its internal organs (p. 30).

*GADWALL. *Chaulelasmus streperus.*

Recorded as succumbing, but never in great numbers, at Great Salt Lake, Utah; in North Dakota; at Lake Newell, Alberta; and in the Klamath Lake district in southern Oregon.

*BALDPATE. *Mareca americana.*

Found dead in most of the principal duck-sickness areas. At Tule Lake, Calif., the number afflicted, though limited, was large in proportion to the total number of this species present.

*American Pintail. *Dafila acuta tzitzihoa.*

Probably more pintails succumb to duck sickness than any other single species. Locally or periodically other birds may contribute more to the general mortality, but the breeding range and late-summer concentration and migration movements throw this bird in frequent contact with disease areas. This is particularly true in central and southern Oregon and throughout California.

*Green-winged Teal. *Nettion carolinense.*

Green-winged teal die in great numbers at all principal points of infection. When birds are being rescued the little teal often succumb in the process of handling. One seldom finds utterly prostrate teal in the field—they usually are mildly affected, possibly just contracting the disease, or are dead.

Blue-winged Teal. *Querquedula discors.*

Dead birds reported from Kidder County, N.Dak., by Uhler in August 1929; and from Lake Newell, Alberta, by Munro in 1925.

*Cinnamon Teal. *Querquedula cyanoptera.*

A common bird about Tule Lake, Calif., through the seasonal period of sickness. Fewer cinnamons, however, perish than green-wings, which flock in during migration.

*Shoveler. *Spatula clypeata.*

Sick "spoonbills" were reported from all the main duck-sickness areas. They display a relatively low resistance to the disease, and many perish even though rescued and given good care.

*Redhead. *Nyroca americana.*

Observations at Tule Lake bear out those by Wetmore at Great Salt Lake to the effect that redheads, particularly birds of the year, perish in large numbers. It would appear that the feeding habits of these young lead them to ingest toxic material more frequently than do adults.

Ring-necked Duck. *Nyroca collaris.*

Archie V. Hull has found a few ring-necked ducks afflicted with duck sickness on the Bear River Marshes, Utah, in recent years.

Canvasback. *Nyroca valisineria.*

In the severe late-season outbreak of 1932 in Willard Spur, Utah, numbers succumbed to the disease. These birds do not ordinarily arrive in the infected areas about Great Salt Lake until after the malady has subsided.

Lesser Scaup Duck. *Nyroca affinis.*

The migration of "bluebills" is not early enough to bring many into sickness areas in this country until after the most toxic period. Sick birds have been reported, however, at Lake Newell, Alberta, by Munro in 1925; and at the Bear River Migratory Bird Refuge, Utah, by Hull in more recent years.

American Golden-eye. *Glaucionetta clangula americana.*

The golden-eye has been found a victim of duck sickness at Lake Malheur (September 1929) and at Great Salt Lake (November 1932).

Buffle-head. *Charitonetta albeola.*

In November 1932, a number of these birds were afflicted with duck sickness in areas adjacent to Willard Spur, at the north end of Great Salt Lake. Usually the disease has disappeared by the time these late migrants arrive in numbers.

*Ruddy Duck. *Erismatura jamaicensis rubida.*

Not a common victim of duck sickness.

Red-breasted Merganser. *Mergus serrator.*

In November 1932, one dead and several affected mergansers which, in all probability, had ingested toxin were found in the Willard Spur section of Great Salt Lake.

Marsh Hawk. *Circus hudsonius.*

Marsh hawks affected apparently by botulism have been noted by Lincoln, at Big Alkali Lakes southeast of Dawson, N.Dak. (1929); by Hull, on the Bear River Marshes, Utah; and by Kalmbach, at the mouth of the Blitzen River,

Lake Malheur, Oreg. (1929). The carrion-feeding habits occasionally indulged in by these birds may explain the contraction of the malady. One partially paralyzed and flightless individual was found at Lake Malheur stranded on a small clump of tules to which the current had drifted the body of a teal on which it was feeding.

PRAIRIE FALCON. *Falco mexicanus.*

A juvenile individual found dead on the algal beds of Tule Lake, October 10, 1930, is the basis for including this species among the victims of duck sickness. The bird was in excellent flesh, with no signs of death by shooting or bodily injury, nor with any marked pathological lesions, a characteristic condition of birds succumbing to botulism. A culture made of its liver, removed under sterile conditions, revealed *C. botulinum*, type C. The fact that the bird was young would account for the possibility of this naturally predacious species having fed on a dead specimen in which toxin had been formed.

DUCK HAWK. *Falco peregrinus anatum.*

One bird found by Hull on the Bear River Marshes, was in a helpless condition and exhibited all the characteristic symptoms of duck sickness.

RING-NECKED PHEASANT. *Phasianus colchicus torquatus.*

Included on the basis of observations made by Uhler at the scene of an outbreak of duck sickness at Lake Poinsett, Hamlin County, S.Dak., in September 1929.

*AMERICAN COOT. *Fulica americana americana.*

A frequent victim of duck sickness, yet in the outbreaks encountered by Kalmbach the number succumbing was proportionately small compared with the total number of coots present.

*KILLDEER. *Oxyechus vociferus vociferus.*

An occasional victim at Great Salt Lake and in the areas covered by this study, but at Lake Newell, Alberta, killdeers comprised about 4 percent of the affected birds in 1925 (*51, p. 78*).

AMERICAN GOLDEN PLOVER. *Pluvialis dominica dominica.*

A single specimen, apparently affected with duck sickness, was picked up on the Bear River Marshes by Hull in the summer of 1932.

BLACK-BELLIED PLOVER. *Squatarola squatarola.*

Affected birds have been reported within recent years by Munro at Lake Newell, Alberta (*51, p. 78*), and by Hull at Great Salt Lake, Utah.

RUDDY TURNSTONE. *Arenaria interpres morinella.*

Reported affected at Lake Newell, Alberta (*51, p. 78*).

EASTERN SOLITARY SANDPIPER. *Tringa solitaria solitaria.*

Noted sick by Uhler, at Long Lake, Kidder County, N.Dak., in August 1929.

WESTERN WILLET. *Catoptrophorus semipalmatus inornatus.*

Reported affected at Lake Newell, Alberta, by Munro, in 1927, (*51, p. 78*) ; and at Long Lake, southwestern Kidder County, N.Dak., by Uhler, in 1929.

*LESSER YELLOW-LEGS. *Totanus flavipes.*

A few have been found affected in several of the important sickness areas.

AMERICAN KNOT. *Calidris canutus rufus.*

The single record is based on a specimen found by Munro, at Lake Newell, Alberta, in 1925.

*PECTORAL SANDPIPER. *Pisobia melanotos.*

BAIRD'S SANDPIPER. *Pisobia bairdi.*

Reported affected and dying in considerable numbers at Lake Newell, Alberta (*51, p. 78*).

*LEAST SANDPIPER. *Pisobia minutilla.*

Recorded dying in limited numbers at Great Salt Lake by Wetmore. A few dead specimens also were collected by Uhler at Long Lake, Kidder County, N.Dak., in 1929. Extensive mortality occurred at Tule Lake, Calif., in the sum-

mer of 1931 among these diminutive shore birds which were obtaining much of their food from the larvae and pupae of hydrophilid beetles, the cocoons of which were formed on the upper surface of the algal beds (p. 13). A considerable number also were found dead on the borders of overflowed wheatlands northwest of Tule Lake in the summer of 1929.

*Red-backed Sandpiper. *Pelidna alpina sakhalina.*

Recorded by Wetmore as dying at Tulare Lake, Calif.

*Long-billed Dowitcher. *Limnodromus griseus scolopaceus.*

Not a frequent victim of duck sickness.

Stilt Sandpiper. *Micropalama himantopus.*

Recorded by Munro as dying at Lake Newell, Alberta, in 1925.

*Western Sandpiper. *Ereunetes mauri.*

These birds possessed the same habits and shared the same fate as the least sandpipers at Tule Lake, Calif., in 1931.

*Marbled Godwit. *Limosa fedoa.*

At Lake Newell, Alberta, duck sickness has been recorded as occasionally destructive to marbled godwits. At that lake in 1925 these birds comprised more than 6 percent of the total dead (*51, p. 78*).

Sanderling. *Crocethia alba.*

A single dead specimen was recorded by Munro in the course of the outbreak at Lake Newell, Alberta, in 1925. In recent years the species also has been found affected at Great Salt Lake by Hull.

*Avocet. *Recurvirostra americana.*

Probably more avocets die of duck sickness than any other species of shore bird. This statement is made in full cognizance of the fact that sick or dead avocets are conspicuous objects and are easily detected while the least and western sandpipers which also die in great numbers may easily pass unnoticed. Affected avocets have been reported from all the principal duck-sickness areas. They early lose control of their leg muscles and, once down, seldom regain the ability to stand, even under conditions favorable to their recovery.

* Black-necked Stilt. *Himantopus mexicanus.*

Occasional sick or dead stilts were found in the course of the field work incident to this study. Wetmore, however, found them dying about Great Salt Lake in numbers second only to the avocet among the group of shore birds. Once they have lost the ability to stand, they are doomed, since, aside from the effect of the disease itself, the birds often are confronted with feather soaking, and entanglement in the masses of algae, from which they seldom free themselves.

Wilson's Phalarope. *Steganopus tricolor.*

Sick birds have been found at Tule Lake, Calif., by Kalmbach; and at Great Salt Lake, Utah, by Lincoln, in 1926.

Northern Phalarope. *Lobipes lobatus.*

In 1929 a considerable number of migrating individuals came to Tule Lake at a time when duck sickness still was prevalent, and a few contracted the disease.

Parasitic Jaeger. *Stercorarius parasiticus.*

A single individual affected apparently with duck sickness, was found in 1932, by Hull on the Bear River Marshes, Utah.

* California Gull. *Larus californicus.*

The first indication of duck sickness in each of the three seasons devoted to the study was manifested among juvenile gulls on an island in an irrigation catch basin, 10 miles south of Klamath Falls, Oreg. In 1930 and 1931 young California gulls were the first to succumb, and in 1929 a young ringbill gave first indication of the seasonal outbreak. These young gulls were raised on a mixed diet of insects (mainly grasshoppers), crawfish, and fish. The nesting ground was littered with uneaten or regurgitated food, which easily might serve as a suitable incubating medium for the toxin of botulism. The greater part of this early mortality was confined to the young gulls; the older birds

apparently were not ingesting toxic material so frequently. Later in the season when gulls were found generally distributed throughout the irrigated sections and about Tule Lake, only an occasional sick one was found. This gull has also been reported as succumbing at Great Salt Lake, Utah (*71*), and at Lake Newell, Alberta (*51*). The fact that more of these carrion feeders are not killed may be due to their tolerance of the toxin (p. 44).

* Ring-billed Gull. *Larus delawarensis.*

Observations with respect to ring-billed gulls and duck sickness closely parallel those made on the California gull.

Franklin's Gull. *Larus pipixcan.*

Munro found Franklin's gulls dying in considerable numbers in the outbreak of duck sickness at Lake Newell, Alberta, in 1925 (*51*), and Uhler and Lincoln reported them at two points in Kidder County, N.Dak., in 1929. A single bird found sick at Tule Lake, Calif., July 31, 1931, displayed all the characteristic symptoms of the disease, and when well on the road to recovery suffered a relapse, precipitated perhaps by its having been fed the flesh of other birds that had died of the disease.

Bonaparte's Gull. *Larus philadelphia.*

The only known cases of duck sickness in this species were two sick and several dead individuals found at Tule Lake, Calif., July 31, 1931.

*Forster's Tern. *Sterna forsteri.*

*Black Tern. *Chlidonias nigra surinamensis.*

Individuals dying apparently from duck sickness have been found at Great Salt Lake (Wetmore) (*71*); at Long Lake, Kidder County, N.Dak. (Uhler); and at Lake Newell, Alberta (Munro) (*51*).

*Horned Lark. *Otocoris alpestris* subsp.

Found affected at Lake Bowdoin, Mont. (*71*).

*Northern Cliff Swallow. *Petrochelidon albifrons albifrons.*

On the Bear River Marshes, Utah, Wetmore found several swallows that revealed typical symptoms of duck sickness. D. D. McLean also has reported sick cliff swallows in California (as published by Hobmaier (*40, p. 11*)).

*American Magpie. *Pica pica hudsonia.*

This is one habitual carrion feeder that has not developed an immunity to type C botulism. Wetmore noted sick magpies on the Bear River Marshes in Utah, that frequently had fed on bodies of birds that had died of duck sickness.

*American Pipit. *Anthus spinoletta rubescens.*

Western Meadowlark. *Sturnella neglecta.*

Reported affected in California by McLean (*40, p. 11*).

* Yellow-headed Blackbird. *Xanthocephalus xanthocephalus.*

In addition to Wetmore's record, Sperry found afflicted yellowheads in the Klamath Falls area in 1927.

Nevada Red-winged Blackbird. *Agelaius phoeniceus nevadensis.*

Redwings afflicted apparently with duck sickness were noted by Sperry in the Klamath Falls area in 1927.

* Rusty Blackbird. *Euphagus carolinus.*

Reported by Wetmore at Lake Bowdoin, Mont.

Brewer's Blackbird. *Euphagus cyanocephalus.*

Afflicted individuals were found in the Klamath Falls area in 1927, 1929, and 1931, on ditch banks adjacent to overflowed land where ducks were dying in considerable numbers.[11]

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[11] In addition to this list, mention may be made of two other species recorded in the literature of botulism: Dickson (*15*) has noted the susceptibility of a "wild canary" (goldfinch, *Spinus* sp.); and Hart (*33*) that of the California linnet, or common house finch (*Carpodacus mexicanus frontalis*). In each of these instances, however, the virulent toxin of type A botulism may have been involved.

Besides the foregoing records of species of North American wild birds afflicted with duck sickness, mention should be made of several South American birds known to have succumbed to the same malady under field conditions. These records were submitted by Wetmore, who from his earlier studies at Great Salt Lake was thoroughly familiar with the symptoms of the disease. He encountered an outbreak of duck sickness while engaged in ornithological studies in Uruguay in 1921. At Laguna Castillos, near San Vicente de Castillos, about 400 miles east-northeast of Buenos Aires, he recorded on January 31, 1921, the following:

> The shores of the lake were alkaline. . . . I noticed a few dead coots strewn along without paying particular attention until I picked up a living brown-headed gull (*Larus maculipennis*) in a helpless condition. Struck by its appearance, I examined it closely and was astonished to discover the unmistakable symptoms of duck sickness. . . . A short distance farther on I found a Trudeau's tern (*Sterna trudeaui*) in the same condition. About 40 coots (*Fulica armillata*), 10 southern pintail (*Dafila spinicauda*), 2 lapwing (*Belonopterus chilensis lampronotus*), and 2 brown-headed gulls were found dead in a distance of a quarter of a mile.

Domestic poultry may contract duck sickness in environments and in a manner similar to that experienced by wild birds. It would appear that domestic ducks of all breeds may succumb when they have access to areas where toxin is being produced. Late in the summer of 1928 an entire flock of domestic ducks of several breeds, belonging to a rancher living southwest of Klamath Falls, Oreg., perished from what appeared to have been typical duck sickness. These birds had had access to an alkaline pond about which shore birds also died. In 1931 the body of an avocet found on a small island in this pond revealed *Clostridium botulinum*, type C.

During a severe outbreak of duck sickness at Long Lake, southwestern Kidder County, N.Dak., in 1929, Uhler noted mortality among domestic chickens and turkeys that had wandered into an area where wild birds were affected. Similar mortality was reported near Cone, Crosby County, Tex., during an outbreak in 1930. Instances such as these indicate that conditions that produce duck sickness among wild birds likewise may constitute a direct menace to domestic birds. Under the conditions of domestication the contraction of duck sickness (limberneck) ordinarily is associated with the presence of localized sources of toxin, as individual carcasses of birds or mammals to which poultry have access. When these are removed the trouble ceases. Domestic ducks have been known to perish under conditions of general stagnation created in small artificial ponds in which the essential features of a naturally infected environment are closely simulated. Mention may be made of the death of a number of Nile geese, gray-backed ducks, and other species in the National Zoological Gardens, in Pretoria, South Africa, in December 1928 (*56*). A similar outbreak had taken place 3 years before but was not investigated. Although the actual toxin-producing medium was undetermined, the suggestion was made that the bodies of earthworms may have supplied it. Cultures made from material collected in this outbreak had not been typed at the time the initial report on the case appeared, but it has been learned, through subsequent correspondence with E. M. Robinson, of the Department of Agriculture

of the Union of South Africa, that all avian cases of botulism investigated in South Africa have been of type C.

A somewhat similar case, resulting in the death of numerous ducks and two swans, has been reported in American literature (*54*). In this instance reported by Palmer and Baker, in 1922:

> The lake was stocked with fish. About the middle of September numerous dead fish and tadpoles were observed floating along the shores. Some of the dead tadpoles and small fish were ingested by the ducks and swans, and soon thereafter the ducks began showing symptoms of botulism . . . One swan died in about 24 hours after showing clinical symptoms of botulism.

The type of botulism involved in this outbreak was not determined.

Botulism naturally contracted has been recorded in domestic ducks of unnamed variety and ostriches in South Africa (*66, p. 1292*). It was inferred that the ducks had ingested carrion and that the ostriches had contracted the malady by feeding on bones in which toxin had been produced.

Several species of birds have been employed in experimental work with type C botulism. Chickens of various breeds, as well as domestic ducks, have been used by research workers in the study of limberneck in this country. Domestic ducks, turkeys, and pigeons, as well as ostriches, have served the same purpose with respect to lamsiekte in South Africa. In the course of the present study domestic pigeons were used almost exclusively in the course of bacteriological work. It was found that they could be easily obtained and kept in captivity; that they are readily susceptible to doses administered interperitoneally; and, through their use, the employment of valuable migratory waterfowl in experimental work was obviated.

## SUSCEPTIBILITY OF BIRDS

Little is known of the actual or relative susceptibility of different species of wild birds to type C *botulinum* toxin. Extent of mortality or affliction as encountered in the field cannot be taken as an index, for the reason that numerous factors other than abstract susceptibility play important roles in its determination. The number of affected birds that will be found is usually in proportion to the abundance of each species on the infected areas. The sudden influx of a great number of migrants, with a resultant increase in mortality, has led some observers to conclude that nonresident birds are more susceptible than those reared in infected areas. The present investigation has brought forth nothing, however, that would indicate immunity in birds after one or more contacts with the disease in the field.

Food preferences or feeding habits also may throw this or that species into more or less intimate contact with the toxin of botulism. Late in the summer of 1930, and again in 1931, thousands of Canada and white-fronted geese frequented areas adjacent to Tule Lake, where ducks and shore birds were dying in considerable numbers, yet in the course of the two seasons only five sick geese were found. The browsing and grainfield-feeding habits of these birds in distinction from the puddling habits of the ducks quite effectively prevented their ingesting the toxin generated on the infected mud flats. During the season of 1931 the many least and western sandpipers that

perished at Tule Lake were feeding extensively on larvae and pupae of hydrophilid beetles in cocoons formed in the masses of algae on which these diminutive shore birds walked in search of food. The finding of the remains of many of these larvae in the stomachs of the dead, coupled with the demonstration of *Clostridium botulinum*, type C, in some of the dead larvae, strongly suggests the particular medium through which these birds, and probably few other species, obtained a lethal dose of toxin. At the same time and in close proximity, large flocks of long-billed dowitchers, probing in the mud beneath a shallow but moving sheet of water, almost completely escaped the malady, either because they were not regularly ingesting suitable toxin-producing food or because the steady flow of water was diluting preformed toxin to a degree that made it harmless.

That the extent of mortality cannot be used as an index to the degree of susceptibility is further brought out by the fact that, in judging abstract susceptibility the element of body weight must be considered. Although it is apparent that larger birds would ingest relatively greater quantities of toxic material in feeding it is obvious that under the varied vicissitudes confronting the birds in the field, the ratio would be by no means constant. For instance, to demonstrate relative susceptibility between least sandpipers and Canada geese on the basis of the numbers of dead found, one would have to show, among all other factors previously mentioned, that the geese were regularly ingesting about 150 to 200 times as much toxic material as the sandpipers.

An insight into the matter of relative and actual susceptibility was obtained, however, in the course of experimental work with captive birds. To determine relative susceptibility, an experiment was conducted with 8 green-winged teal and 16 pintails, injected intraperitoneally with a diluted, filtered culture of type C *botulinum*. It was found that the minimum lethal dose of this rather weak filtrate was about 0.025 cc for the green-winged teal (average weight, 255 g), and 0.05 cc for the pintails (average weight, 600 g). This indicated little difference, when body weight is taken into consideration, in the susceptibility of the two species.

An index of the relative susceptibility of these ducks and of domestic pigeons was gained from an experiment run concurrently with the one just described and with the same lot of toxin, so there could have been no differences from changes in potency of culture. Sixteen pigeons were employed, each weighing approximately 350 g. It appeared that the minimum lethal dose for pigeons was not far from 0.0002 cc of this filtrate injected intraperitoneally. From the experiment previously discussed, it may be inferred that the minimum lethal dose for the green-winged teal, weighing about 255 g, is approximately 125 times that for pigeons. Likewise it may be concluded that the minimum lethal dose for the pintail is about 250 times that for pigeons. Converting these manifestly meager data into an appraisal of abstract susceptibility to intraperitoneal doses, by allowing for the element of body weight, it may be concluded that in general the domestic pigeon (350 g) is 175 times as susceptible to the toxin of type C botulism as the green-winged teal (255 g), and 146 times as susceptible as the pintail (600 g).

In the course of experimental work in 1930 an insight was obtained regarding the relative susceptibility of gulls and ducks to oral doses. Extensive use was then made of the incubated livers of birds that had died of duck sickness. This served as an excellent toxin-producing medium, and by feeding it in capsules to experimental birds it was found that botulism could be produced (pp. 55–56). In one experiment 0.5 g of such toxic liver, of which an equivalent amount fed orally had killed a mallard, failed to produce symptoms in a juvenile ring-billed gull. In other experiments it was demonstrated that juvenile ring-billed gulls are at least 20 times more tolerant to oral doses of type C toxin than are adult pintails.

This marked difference in susceptibility of ducks and gulls to the oral assimilation of the toxin is not duplicated when the toxin is administered by injection. Experiments in which ring-billed gulls, mallards, and pintails were used indicated that the minimum lethal dose by injection varied little one from another.

An idea of the quantity of toxic material of moderate potency that must be ingested by wild birds to produce the disease was gained from feeding experiments, in which the incubated livers of birds dying of the disease were used. It was found that 0.1 g of such material given orally to a pintail produced a typical, protracted, and fatal case of duck sickness. In another instance 0.2 g of toxic liver produced a typical sublethal case in a female domestic mallard weighing 1,162 g, but the same dose did not affect a 1,717-g male domestic mallard. In 8 experiments 0.25 g of such toxic liver was sufficient to kill pintails and mallards, and in 4 others less toxic material, in equivalent doses, produced typical symptoms but not death. In no case in which the material was demonstrated to be toxic did a duck survive an oral dose as great as 0.5 g. As this quantity of material bulks about the size of an average pea, it will be seen that the lethal dose for a duck feeding in the field on any equally toxic material is relatively small. Such results lead to the conclusion that in the field, where a high percentage of the naturally produced cases are sublethal, the birds must be ingesting either very small quantities, or that the toxin involved is of low potency. Hobmaier has indicated the possibility of producing the disease by repeated small doses, any one of which would have no effect (*40*).

As few as 10 small dead sarcophagid larvae, weighing together only 0.1 g, contained enough toxin to kill a male pintail 4 days after they were ingested. Fifteen somewhat larger sarcophagid larvae fed to each of two mallards caused death in 19 and 36 hours, respectively. When in later bacteriological work a standardized beef-heart-peptone medium was used, 0.5 cc administered orally was found to kill a pintail in about 45 hours.

Gunnison and Coleman (*29*) demonstrated that the minimum lethal dose for pintails was from 100,000 to 200,000 guinea-pig minimum lethal doses of toxic culture, given by mouth. They also showed that the ratio of the injected to the oral minimum lethal dose of this strain of type C *botulinum* is, for the pintail, from 1:10 to 1:50. This is in contrast to a proportionately much greater oral dose recorded for small laboratory mammals (p. 47).

Pigeons studied in relation to lamsiekte in South Africa, proved decidedly refractory to the toxin of this cattle disease both when treated orally and subcutaneously (*66, p. 1115*). It is possible that future studies may corroborate this marked difference in the action of type C of Bengtson and of type D, which is now looked upon as the bovine strain in South Africa.

The marked resistance of chickens to the toxin of type C botulism administered orally has been demonstrated. Graham has shown that some chickens may without ill effect ingest in single massive doses as much as 1 g of toxic culture to 30 g of body weight (*26, p. 28*). Bengtson (*3, pp. 68–69*) reports that 250,000 guinea-pig minimum lethal doses fed to a 1,180-g chicken produced severe symptoms, though the bird recovered, and comments further on type C toxin to the effect that "the toxin in carrion material or fly larvae is probably in much more concentrated form." In any event, the effects produced on chickens feeding under natural conditions, as in the case of wild birds, are dependent on the quantity of material eaten. Bengtson records that 25 cc of a culture in a cooked-meat medium, fed to a 1,200-g chicken, produced typical symptoms in 70 hours and eventually death. The resistance of chickens has been noted even when the toxin of type C is administered by injection, although the minimum lethal dose in such cases is somewhat less than a tenth of the lethal oral dose.

Of interest in the matter of avian susceptibility to botulism is the reaction of the turkey buzzard, which, by reason of its feeding habits, has for ages been thrown in intimate contact with the toxin elaborated by *Clostridium*. Through the cooperation of officials of the National Zoological Park, Washington, D.C., four of these birds were obtained for experimentation. An oral dose of 30 cc of a type C culture (of which a 0.0001-cc intraperitoneal dose was sufficient to kill a pigeon) failed to have any effect. Intraperitoneal doses of 1, 5, and 10 cc likewise produced no symptoms, and a dose of 15 cc caused only a slight, temporary weakness in the legs and wings about 24 hours after injection. A culture of type A of fair potency (the minimum lethal dose for a guinea pig being between 0.001 and 0.0001 cc, intraperitoneally) also produced no effects with injected doses of 1 and 5 cc. However, 10 cc caused a slight, temporary impairment of locomotion 2 days after administration. The most startling results were obtained with a highly potent type B culture (the guinea-pig minimum lethal dose being 0.00005 cc by injection). Intraperitoneal doses of 5, 10, and 15 cc failed to produce any noticeable symptoms. The last of these doses was the equivalent of 300,000 guinea-pig minimum lethal doses, and indicated a tolerance expressable by the ratio of 0.04 cc of injected toxin for every gram of body weight.

## OTHER ANIMALS AFFECTED

Little is known of the effect of duck sickness under field conditions on wild creatures other than birds. Wetmore (*71, p. 12*) stated that duck sickness affected muskrats and that at times frogs (*Rana pipiens*) died apparently from the same cause at Great Salt Lake.

He also suggests that even certain aquatic beetles (*Cybister* and *Dytiscus*), predacious in habits, may have been affected.

Dead muskrats were found in 1929 at the scene of a duck-sickness outbreak in Day County, S.Dak., by Uhler. In the same year W. H. Ransom reported muskrats dying near Hamer, Idaho, in the course of a similar outbreak. In the summer of 1927 Sperry found a dead weasel (*Mustela*) near Klamath Falls under conditions indicating that it might have contracted duck sickness through feeding on the bodies of dead ducks. In none of these instances involving the death of vertebrates, other than birds, were symptoms noted, nor was bacteriological evidence of the nature of the malady obtained. It is important, however, to consider the possibility of mortality among lower and more abundant forms of life, not only because of its direct effect on these, but also because, by the death of large numbers of small inconspicuous forms, the quantity of possible toxin-producing media is increased.

It has been well established that the more toxic forms of A and B *botulinum* affect a great variety of organisms, ranging from copepods, earthworms, snails, tadpoles, frogs, and fishes (*57*) to higher vertebrates, including such diverse forms as rats, cats, dogs, pigs, horses, goats, cattle, monkeys, and man himself. Less is known of the susceptibility of organisms to the toxin of type C, yet experimental work has brought out the fact that numerous vertebrates other than birds, as well as possibly certain invertebrates, are susceptible to the toxin of the type causing duck sickness. In the course of the present investigation evidence pointed to the susceptibility of copepods (*Cyclops serrulatus*). Inconclusive results were obtained in experiments with snails (*Goniobasis silicula*) and crawfishes (*Astacus klamathensis*). Toads (*Bufo boreas*) were refractory to oral doses, and even when toxin was injected in extremely large doses the results indicated a high degree of resistance.

In the study of type C both in this country and in South Africa the susceptibility of a number of mammals has been demonstrated. Among those commonly used in experimental work are white mice, guinea pigs, and rabbits, of which the first are the most resistant. In South Africa, goats, sheep, and cattle, which come in contact with lamsiekte under natural conditions, were found to be particularly susceptible.[12] Horses, mules, and donkeys were more tolerant of the poison, while rats, dogs, and pigs displayed a resistance that approached, if it did not actually reach, complete immunity. Essentially the same results were attained by Graham and Boughton (*26*) in this country with such of these mammals as they had used, namely, guinea pigs, rabbits, dogs, cattle, and horses. Of particular interest are the reactions of monkeys to the toxin of type C *botulinum*. Gunnison and Meyer (*32*) found that these mammals are resistant to large doses of both types C and D toxin when given by mouth, though they are susceptible to injected doses.

Recently Gunnison and Coleman (*29*) have shown that, "while small laboratory animals were highly susceptible to the toxin of the duck strain when injected subcutaneously, they were remarkably resistant when it was administered by mouth." They also brought out

[12] Comments on the susceptibility of mammals in experimental work in South Africa are based on work done before types C and D had been differentiated.

the fact that the ratio of the injected to the oral minimum lethal dose was, for guinea pigs, 1:1,800; for mice, 1:22,000; and for rabbits, 1:14,800.

## HUMAN BEINGS AND TYPE C BOTULISM

When duck sickness first attracted national attention, there was considerable apprehension as to the possibility of human infection. In the absence of a satisfactory diagnosis of the malady and in view of the wide-spread use of wild fowl as food, this fear was by no means without reason. Some hesitated to handle the sick and dead birds, and there were rumors of the contraction of the disease by people. That was in the days when the alleged causes of the malady ranged from typhoid, through the whole gamut of avian diseases, to direct intoxication by arsenic or other poisons from industrial waste. Even persons inclined to meet such emergencies without hysteria urged disinfection of ducking grounds, and this led to the practice of burying the dead bodies or covering them with lime (p. 33). Some duck clubs were closed during seasons of severe outbreak, but this was prompted not alone by a feeling that there were dangers involved through the human consumption of the flesh of affected birds, some of which still could fly, but also by a genuine desire to conserve the remaining birds.

There is no question that many ducks affected with duck sickness at the time they were killed have been eaten by human beings. Many birds also were being picked up accidentally by hunters who mistook those killed by disease for those they had shot. In the days of market hunting in California, it was common knowledge that unscrupulous hunters made it a practice to gather birds affected with or recently dying of the disease, fire lead shot into their bodies, and offer them for sale.

This study has revealed no instance of human beings contracting botulism through eating the flesh of bird victims of duck sickness. In considering the susceptibility of man to type C botulism this fact is indeed significant. Although one would have to presuppose an adequate toxin-producing period in the flesh eaten and the absence of heat great enough to destroy toxin or the organism itself, many prefer their game rare and a bit "high", a preference that might easily lead to serious consequences were type C *botulinum* toxic to man. These circumstances lend further credence to the belief that types A and B *botulinum* are seldom causative factors in epizootics of duck sickness under natural conditions (p. 61). Further circumstantial evidence of the relative if not absolute immunity of man to oral doses of the toxin of type C, and possibly the closely associated type D, comes from South Africa, where in areas known to be infected with lamsiekte, the natives often may be found feasting on meat that is none too fresh.

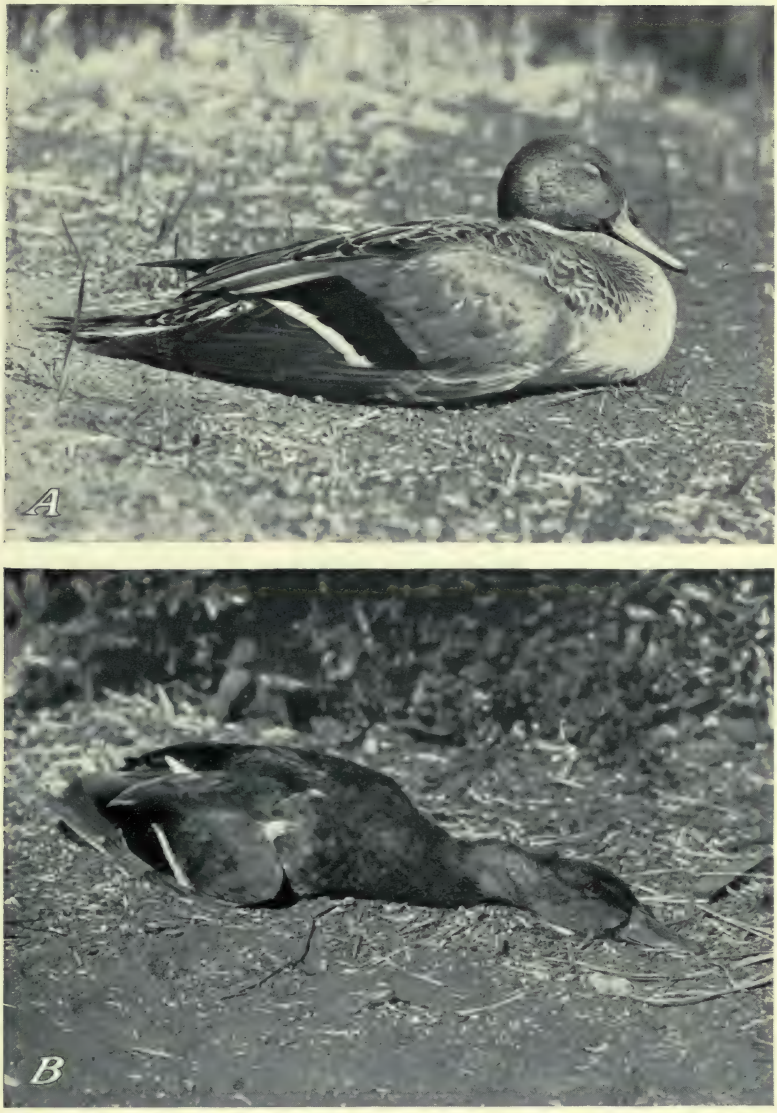
Recent experimental work by Gunnison and Meyer with type C botulism on monkeys (*Macacus rhesus*), from which analogies may be drawn with respect to its action on man, indicates that "they are resistant to large amounts of types $C_\alpha$ [= C of Bengtson] and D toxins when given by mouth, although readily intoxicated when injected subcutaneously" (*30*, *32*).

## SYMPTOMATOLOGY

The general clinical picture of duck sickness (botulism) is one of extreme muscular weakness, brought about by an involvement of nerve centers or terminals (*18*). In wild birds this early results in inability to fly and then to walk, followed later by loss of muscular control of the neck, a paralysis, in many cases, of the muscles controlling the nictitating membrane, as well as those affecting pulmonary action, and, in the end, utter prostration, with death ensuing usually without struggle or apparent pain. A diarrhea marks some cases, followed often by an obstruction of the vent by hardened renal matter. Subnormal body temperature is a common symptom. A high percentage of recovery also results when birds are rescued from infected environments and afforded dry quarters, wholesome food and water, and some individual attention.

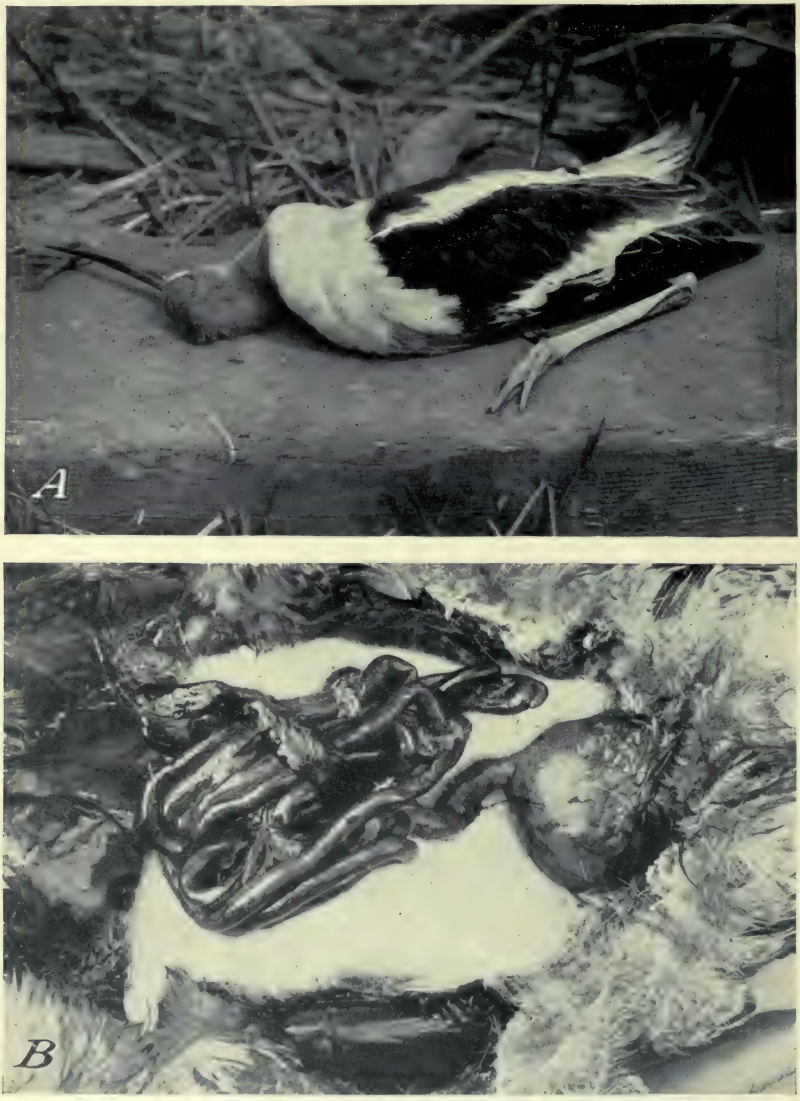
In duck sickness, as with most other intoxications, the rapidity of onset and the severity and even character of the syndrome are dependent upon the quantity of toxin ingested. Stating the case somewhat differently Theiler, writing of the analogous malady lamsiekte in South Africa, said: "It is possible to produce almost any clinical form of the disease at will by adjusting the dose of toxin" (*66, p. 1116*). Although a certain period must elapse between the time of ingestion and the manifestation of the initial symptoms, this may vary in birds from less than 2 hours (in the case of an experimental pigeon that had received an excessive subcutaneous dose) (*66, p. 1291*) to as much as several days or a week, when the affliction is mild and followed by recovery. Such differences in the quantity of toxin assimilated produce cases that may be acute or subacute, and when a paralysis or weakness persists after partial recovery, the disease may acquire even a chronic aspect. Among wild ducks subacute cases predominate, and acute ones are not uncommon. Those that may be considered chronic are rare and usually run into complications that tend to obscure the immediate cause of death. In describing in detail the nature and sequence of symptoms, a subacute, sublethal case will first be discussed.

Prior to the discovery of the cause of duck sickness and the means for infecting experimental birds, some of the early symptoms could not be observed for the reason that wild birds so affected could fly or otherwise evade capture. In the case of a mallard that has ingested a quantity of toxin somewhat less than lethal, one may expect to see the first uncertain symptoms about 24 hours after ingestion. The bird has a tendency to rock forward, throwing its weight onto the toes. At this time it still can use its wings vigorously, even though unable to maintain prolonged flight. The slight uncertainty of equilibrium soon is aggravated and followed by an unsteadiness on the feet, revealed as a halting gait and an inclination not to move. Later the bird assumes a straddle-legged position while standing, and its efforts to walk are confined to short, hesitant steps in which is revealed for the first time the physical weakness invading its system. Even prior to the appearance of the first noticeable symptoms afflicted birds refuse food and water, a circumstance that readily explains the almost total absence of food in the stomachs of birds that die of duck sickness.




B37948 B36816

*A*, Sick pintail, unable to fly or walk; inclined to rest its bill on the crook of the neck; its nictitating membrane paralyzed. *B*, Mallard in the final stages of duck disease. Birds so affected are utterly prostrate, respiration is slow and feeble, and the heart action weak.




B36840 B35589

*A*, Sick avocet in which antagonistic muscles are unequally paralyzed, resulting in the torticollis shown in the neck of this bird. *B*, Viscera of juvenile ring-billed gull, showing distention of cloaca and lower intestine caused by stoppage of vent, a condition often found in gulls and avocets dying of duck sickness.

At this point, about 30 hours after ingestion of the toxin, ability to fly is noticeably impaired, and the bird may not be able to rise from the water. It still can make rapid progress, however, by combined wing and leg action. The body, partly lifted from the water, is dragged over the surface by noisy wing beats. As soon as cover is reached the bird seeks to conceal itself and conserve its declining strength. It still may be able to stand, but its tendency to squat increases, and in doing this it evidences a pronounced weakening of muscles controlling the tibio-tarsal joint. The bird may lower its body normally for a portion of the distance but then suddenly loses control and drops to the ground. Paralysis soon begins to affect some of the muscles controlling the wing, including those that support it when folded next to the body. These relax, causing the "wrist", or carpal, joint to lower, and at times there is a complete wing droop, the primaries touching the ground.

Even after ability to stand or to move the wings is lost, affected ducks still can swim, and when they encounter shallow water or mud flats, they manage to make feeble and uncertain progress by thrusting themselves forward on the breast. In this stage some ducks, particularly redheads, attempt to evade capture by diving, if in deep water. At times, however, redheads and, more frequently, other ducks have difficulty in submerging, owing possibly to their inability to deflate certain air sacs. Birds so affected may be found with the head beneath the surface, paddling more or less vigorously, but making no downward progress.

A number of symptoms more or less closely related to the spread of paralysis to regions of the neck and head appear at about this stage of the syndrome. For some time the bird has been holding its head with the bill resting on the crook in its neck (pl. 3, *A*), but as the victim weakens, inability to maintain an upright posture of neck and head increases, and from time to time the head will pitch forward until the tip of the bill touches the ground, or it will drop to one side or the other, where it may rest for short periods sidewise, or sometimes in an almost inverted position.

Even previous to the arrival of this condition one may detect in many cases a paralysis of the nictitating membrane, that "third eyelid", which in healthy birds flashes backward from the anterior corner of the eye on the slightest irritation. At first this affliction may be indicated merely by a certain sluggishness in the activity of the membrane, but later the bird is unable to draw it across the entire width of the pupil. This results in the drying of the unmoistened portion, where particles of dust soon gather, and often a sharply defined line marks the edge of the area over which the nictitating membrane still functions. Finally the third eyelid becomes wholly inactive and lies inert and concealed at the anterior corner of the eye.

Paralysis of the nictitating membrane, though a common manifestation of duck sickness, is by no means a constant or diagnostic symptom. Geiger, Dickson, and Meyer (*24*) have stated the case properly with respect to barnyard fowl afflicted with limberneck when they said, "*as a rule*, the movements of the nictitating membrane are sluggish . . ." When this symptom appears it may be considered characteristic of the earlier part of the syndrome. In

fatal cases it may persist until the end; in mild ones it may be apparent for only a short period of the bird's disability or, as was demonstrated by experiment, it may not appear at all, even though paralytic conditions exist in other parts of the body. Among birds recovering from duck sickness it is common to have the normal activity of the nictitating membrane restored before full control of legs or wings is regained, and to find this membrane functioning perfectly even in helpless birds whose outer eyelids are completely sealed by hardened exudates. In the course of this investigation, beginning with the observations of Sperry in 1927, individuals that did not reveal a paralysis of the nictitating membrane have been encountered in the field, including the following species: Great blue heron, black-crowned night heron, pintail, coot, killdeer, avocet, ring-billed and California gulls, and yellow-headed, red-winged, and Brewer's blackbirds. Probably at least a portion of these were birds in which the function of the membrane had been restored after earlier impairment.

On the other hand let it be emphasized again that immobility or sluggishness of the nictitating membrane may occur in cases of saline intoxication (p. 21), and hence the symptom cannot be looked upon as diagnostic of duck sickness.

At this point mention of another symptom associated with the eye may be made by quoting directly from Wetmore (*71, p. 9*), who has fully described this aspect of the syndrome:

> Lying within the orbit on the anterior surface of the eyeball is a large gland, known as the Harderian gland. This secretes a fluid that reaches the eyeball at its anterior corner below the nictitating membrane. In the duck sickness this gland always seems more or less affected and in most cases is considerably swollen, so much so, in fact, that the eyes are protuberant. Following this swelling the discharge of colorless, watery fluid from the gland becomes more copious. Normally it escapes at the anterior corner of the eye through two canals that unite and lead into the nasal chamber. In sick birds the secretion becomes greatly augmented, however, until these openings are not able to care for it, the eyes appear watery, and the fluid escapes between the lids. In some pintails kept under observation the escape of this fluid moistened the feathers of the entire side of the head. In a few hours this discharge becomes viscous and more or less opaque, and cements together the eyelids, while the augmenting supply held within puffs out the lids all around. The portion that escapes through the ducts passes through the inner nasal openings into the month. As the opening into the trachea (the glottis) lies immediately below, the fluid clogs it and interferes greatly with breathing. After two or three days the secretion becomes caked and cheeselike. When it thickens in large quantity it sometimes closes the trachea and causes strangulation. In a few cases the fluid penetrated to the bronchi, filling them completely and killing the bird.

Coincidentally with or even prior to the paralysis of the nictitating membrane a dyspnea, or air hunger, may appear. Often the lower mandible drops slightly, and respiration becomes a series of gasps in which the head is raised with each inspiration. This labored breathing, visible at a considerable distance, served as a diagnostic recognition mark in the search for sick birds in the field. It is caused no doubt by impairment of the muscles controlling pulmonary action, coupled in some cases with an obstruction of the glottis, or trachea, as just described.

A greenish diarrhea develops in many ducks between 24 and 48 hours after ingestion of the toxin. At times this is pronounced,

and if the bird has lost its ability to move about, the plumage of the underparts becomes greatly soiled. Here again, as with the paralysis of the nictitating membrane, the symptom covers only part of the period of the bird's disability. After a day or two of profuse watery discharge the white renal matter of the feces increases and tends to harden, resulting, at times, in a complete stoppage of the vent (pl. 4, *B*). In addition to a more or less mechanical obstruction, there may be at this stage an inhibition of gastro-intestinal movements much as in human cases of botulism, in which constipation is a characteristic symptom.

The peak of the syndrome, in cases just sublethal in intensity, usually occurs between 48 and 60 hours after ingestion of the toxin. At that time the bird may be completely prostrate, with the neck outstretched, wings relaxed, and feet beneath it or extending backward (pl. 3, *B*). The presence of life itself may be evidenced only by the rise and fall of the feathers of the back, with the slow and feeble respiration, which, as has been shown by Wetmore (*71, p. 8*) in a mallard, may be as slow as 8 per minute. At the peak of sublethal cases in pintails a respiration rate of 15 to 18 a minute is common. Heart action likewise is enfeebled and retarded, a pulse of 60 to 80 being recorded in a duck instead of the normal of about 120 per minute. Great irregularity in the pulse also is often encountered. This has ranged from 60 per minute when the bird was at rest, to a speed too fast to compute when the victim has been endeavoring to escape capture. Body temperatures are quite uniformly subnormal in all severe cases. From a normal of 104° to 109.8° F. (mean 106.7°) (*71, p. 8*), rectal temperatures of prostrate ducks often may be as low as 100° F., and, when death is near, the body may even feel cool to the touch. In a mallard that was prostrate after ingestion of a lethal dose of toxin the rectal temperature was below the lowest graduation (94°) of the clinical thermometer used.

Signs of recovery in a duck that has ingested a dose slightly less than lethal may be expected on the third or fourth day. If the bird has been prostrate, ability to move and raise the head marks the turn for the better. If the eyelids have been sealed by exudates the bird will reveal its first active effort to regain normal conditions by rubbing these on its back, first on one side and then the other. If water is placed before it, the bird will drink large quantities at this early stage of recovery, even though it may still be unable to see. In doing so it is likely to choke, apparently as a result of a continued impairment of the pharyngeal muscles.

On the fourth or fifth day the bird will preen its feathers and may even rise to its feet. It gives great attention to restoring its plumage to a normal water-shedding condition. Muscular weakness still persists, however, and there may be repeated hitching of the wings in an effort to hold them properly at the sides.

On the fifth or sixth day one may expect to find the bird walking haltingly and even stretching or flapping its wings. Coincidentally, for the first time since its affliction, it will again take food. A day or two more and it will have regained strength sufficient to fly short distances and be able to care for itself when released.

Such is the usual sequence of symptoms in a severe but sublethal case. Greater quantities of toxin will result in a more rapid and

violent syndrome, and often in an inversion of the usual order of some of the symptoms. Occasionally a duck with complete lack of control of head and neck, still retains ability to travel across the water by lusty wing beats; this may cause the head to flop from side to side, and, when progress stops, it may drop beneath the surface of the water. At times nerve impairment may cause a paralysis that is not symmetrical with respect to the two sides of the body. One affected ring-billed gull could stand only if placed with its left side against the wall of its cage; on the open floor it invariably fell to the left. When directly antagonistic muscles are involved, an unequal paralysis may upset the coordinating mechanism and cause a pronounced torticollis. Such a condition is not infrequent among gulls and avocets (pl. 4, *A*). Doses of toxin so excessive as to cause death within a few hours may produce convulsive reactions, whereas in more protracted cases, the victim at no time appears to be in pain other than that incident to difficult breathing. Avocets and stilts become quite helpless when the paralysis affects their long legs. These often become entangled in masses of aquatic vegetation, from which the victims seldom free themselves. Air hunger is a more pronounced early symptom among gulls than ducks. Both gulls and coots may exhibit complete control over the muscles of the head and neck, even to the extent of being aggressively pugnacious, while at the same time their legs and wings are helpless. One ring-billed gull could peck vigorously at a time when its nictitating membrane was completely paralyzed.

Loss of feathers or a looseness of plumage, considered to be of some value in the diagnosis of limberneck in domestic poultry, was not found to be a common attendant factor among wild ducks. Now and then an individual duck would lose many feathers during its period of disability, but part of this at least could be associated with the post-eclipse molt.

A persistent paralysis was noted among some experimental birds after they had recovered from the principal effects of the disease. This was manifested usually by inability to hold the wing properly in place. Occasionally a leg weakness developed that was retained for a week or two after the bird had resumed feeding and other activities. The victims of such chronic disabilities as a rule became much emaciated, took little care of their plumage, and seldom effected complete recovery.

It is evident from field observations that few of the dead birds encountered had experienced the violent symptoms indicated in the experimental work with excessive doses of toxin. Almost invariably dead birds are found lying on the breast, with plumage unruffled and unsoiled except at the vent. Death comes slowly, without struggle, and apparently without pain.

## PATHOLOGY

Birds that succumb to duck sickness are, as a rule, in good flesh, a condition to be expected from the fact that in most fatal cases the period of sickness is relatively brief. Only those that have undergone the ordeal of protracted affliction or have had successive experiences with the malady show appreciable emaciation.

The alimentary tract usually is devoid of food, the gizzard containing merely gravel or the hard, indigestible parts of earlier meals. This state of affairs long has tended to conceal the food items or the nature of the feeding environment directly connected with the contraction of the malady.

Though nothing of pathological significance has been found in the gullet or proventriculus, Wetmore has pointed to a sloughing of the stomach lining at the lower edge of the proventriculus. This condition was present in birds succumbing at Great Salt Lake, though not confirmed with any degree of regularity among birds of the Klamath Falls district. Irritation and congestion of blood vessels of the intestine, though frequent, was by no means constant among birds in southern Oregon and northern California. The small intestine, however, was shrunken and firm to the touch and often contained straw-colored mucoid matter. Graham and Boughton (*26*), discussing the pathology of limberneck, have referred to "petechial hemorrhages and areas of congestion and catarrhal inflammation of the mucosa of the small intestines", and Robinson (*56*) has noted "evidence of catarrhal gastro-enteritis" in a few cases of avian botulism in South Africa.

The larger intestine below the caeca often presents a striking condition that in the case of avocets and gulls becomes almost diagnostic. This consists of an obstruction of the vent due either to the hardening of the renal matter deposited there or to the impairment of muscles controlling the vent, with a resultant accumulation of excretory matter that distends the cloaca often to enormous proportions (pl. 4, *B*). The contents are largely liquid, with varying quantities of granular renal matter.

Other organs of the body appear normal or nearly so. The ventricles of the heart are found in systole. The gall bladder usually is filled and occasionally distended. The lungs, liver, spleen, and kidneys reveal nothing of pathognomonic significance. An erythrocyte count of the blood of sick and healthy birds likewise disclosed no condition of diagnostic value. There appeared, however, an increase of erythrocytes in sick birds, a condition that may possibly have arisen merely from failure to drink for several days.

Dickson has reported that it is common to find hemorrhages in the central nervous system in human beings and experimental animals (*13*, *14*). Engorgement of the blood vessels of the meninges of birds dying of duck sickness, particularly in severe or protracted cases, frequently is revealed at necropsy. Though the hyperemic areas are variable in extent, they are, as a rule, restricted to the surfaces of the medulla, ocular lobes, and posterior half of the cerebrum. Others who have sought for pathognomonic lesions in botulism have called attention to the frequency of disturbances in the central nervous system and its meninges, but as yet nothing that can be considered absolutely specific in character has been detected.

Cowdry and Nicholson (*11*, *p. 836*), after an exhaustive study of the central nervous system in botulism, stated that—

> . . . except for a slight degree of vascular engorgement, all the lesions which we have noted in the brains of mice, guinea pigs, and rabbits suffering from *botulinus* poisoning are readily susceptible of some explanation other than that they are produced by the direct action of the toxin upon the central nervous system.

Dickson, who formerly called attention to apparently diagnostic thrombi in the central nervous system, later stated (*16, p. 77*): "Gross and histologic examinations of the tissues of an animal which has succumbed to botulism fail to show anything that can be considered diagnostic."

If anything may be considered diagnostic of the gross pathology of duck sickness it is the negative evidence created by the lack of any constant or characteristic lesion. In the majority of necropses, however, one may expect to find a certain engorgement of intestinal blood vessels, a hardening of the small intestine, a yellowish mucoid intestinal content, a stoppage of the vent with a resultant distention of the cloaca, and a congested condition in the meninges of the posterior half of the brain.

## DEMONSTRATION OF BOTULISM AS THE CAUSE OF DUCK SICKNESS [13]

### BIRDS USED IN EXPERIMENTS

During 1929 and 1930 much of the experimental work on duck sickness was conducted with wild ducks, gulls, and coots trapped in the Klamath Falls district. When the disease finally appeared in the field and sick birds were being rescued a certain portion of those that recovered were used. During the winter of 1930–31, however, domestic pigeons were employed in experimental work at Washington, D.C., and the satisfactory results attained prompted their continued use during field work in the summer of 1931 and in subsequent experimentation at the University of Minnesota.

Although the use of pigeons in experimental work in botulism had no extensive precedent, it was found, at least when toxin was injected intraperitoneally, that these birds met all essential requirements. Not only are they susceptible to relatively small doses (as little as 0.0001 cc of type C filtered toxin killing in 18 hours in one instance) but they also respond well to toxin-antitoxin tests and reveal a typical and recognizable syndrome. Furthermore, the laboratory use of pigeons had the practical merit of saving valuable wild fowl.

Justification of the use of pigeons in experimental work in botulism has been established by Gunderson in the course of this study. He has shown that—

> mixed (impure) cultures from various sources are ordinarily incapable of causing the death of a pigeon unless *Clostridium botulinum* is present. In one series of experiments involving the injection of materials, either as enrichment cultures or directly from the field, only 4 of the 352 pigeons used died from causes other than botulism. To make the data even more convincing, record of other birds could be added—those surviving toxin-antitoxin injections and those used in subsequent experiments.

Gunderson, using a double series of cultures, one in ordinary broth and the other in the alkaline medium employed in studies of botulism, tested the susceptibility of pigeons to 12 known organisms that might appear as contaminants. A 0.5-cc dose was injected, and only one culture (that of *Bacillus proteus* in ordinary broth) produced ill effects, the pigeon dying with lesions of peritonitis. In subsequent experiments conducted at the University of Minnesota it was

[13] The information here presented has been derived from experiments conducted by Kalmbach in 1929–30, and from data contributed by Gunderson in 1931 and 1932, when facilities for more thorough and accurate bacteriological work were available (*28, 41, 42*).

demonstrated by Gunderson that, whenever *B. welchii* appears as a contaminant, disturbing results are likely to follow. Despite these reactions the uniformly satisfactory results attained in other experiments seem fully to justify the use of pigeons for studying this avian aspect of botulism.

In toxin-antitoxin tests, injections were made into the body cavity directly beneath the posterior border of the sternum. Unfiltered cultures or extracts being tested were injected in 0.5-cc dosages. It was found that when such large doses were employed, symptoms became evident within 36 hours if toxin was present, the usual period being about 12 hours. It should be pointed out, however, that the death of an experimental bird was not accepted as evidence of botulism even though the symptoms pointed to it. Each culture considered to be positive was accepted as such only when toxin-antitoxin experiments confirmed the diagnosis.

Pigeons surviving the injection of cultures could be used again satisfactorily after a lapse of time; but the use of birds that had received antitoxin was considered unwise because the possible creation of an immunity, or the possible presence of residual, uncombined antitoxin. Actual experimentation has indicated that residual antitoxin may be encountered in cases where toxin has been overneutralized and injections made at intervals of from 7 to 10 days.

Serum sensitivity also has been observed in birds receiving antitoxin. In one experiment 7 of 15 previously used birds died of anaphylaxis upon subsequent administration of antitoxin. Others also have noted such a reaction (*23*). Likewise immediate death due to altered antitoxin has been noted in two instances both involving type B antitoxin. That the antitoxin was incriminated is indicated by the fact that substitution of a fresh lot caused this difficulty to disappear (see also comparable results of Topley and Wilson, *68*). Even the injection of cultures alone has produced immediate death in pigeons, with symptoms simulating anaphylaxis, a reaction observed by Hewlett, Bullock, and O'Brien (*36*).

Most of the antitoxins used in this work were obtained from a commercial firm. All type A antitoxin from that source contained antibodies against type C toxin, while those for types B and C were specific.

### REPRODUCTION OF THE SYMPTOMS

The reproduction of the syndrome of duck sickness in experimental birds marked the initial forward step in diagnosis of this malady. This was accomplished (1) by the feeding of incubated body tissues of birds that had died of the disease; then (2) by the injection of normal saline extracts of such toxic material; and, still later (3), by the feeding or injection of standard culture media previously inoculated with material from duck-sickness sources. Opportunity was afforded to note the similarity of symptoms in birds made sick in this manner with those of birds found affected in the field. Cultures of known type C *botulinum*, obtained from a reliable source, likewise produced symptoms typical of duck sickness.

During the latter part of the 1930 field season and in certain experiments conducted during the following winter, incubated body tissues (mainly livers) of birds that had died of duck sickness fur-

nished a convenient source of toxin for experimental work and at the same time afforded evidence of the invasion of body tissues of sick birds by the organism. The material was prepared first by forcing the tissues through the mesh of ordinary pearl-netting fly screen, thus producing a gruellike mass that could readily be measured or weighed. This was then placed for 5 or more days in an incubator, where a temperature of between 85° and 95° F. was maintained. No pains were taken at that time to create an anaerobic condition during incubation. Doses were administered in gelatine capsules, and though crude in technic and involving the use of highly impure cultures, this method proved adequate for the early bacteriological work; later (1931) it was superseded by more approved methods, in which standard culture media and a procedure better suited to the growth of anaerobic bacteria were adopted.

It is fitting to mention a single experiment performed by Sperry in 1927. At that time the idea that duck sickness was in fact botulism, had not been advanced, but an attempt was being made to transmit the mysterious malady by feeding healthy ducks the livers of birds that had died of the disease. A mallard was force-fed a small quantity (about 4 cc) of such tissues daily. At the end of 3 weeks the bird suddenly developed typical symptoms of duck sickness and ultimately died. Today, with a better understanding of the malady, we may surmise what happened in that early experiment: The tissues originally were fresh or nearly so. At some point, however, near the end of the series of doses, the liver used had been kept long enough for the toxin of *Clostridium botulinum* to be formed in quantity sufficient to kill. Although the results of this experiment remained unexplained at that time and for 3 years following, there is now no doubt that Sperry produced true duck sickness in that early experiment.

The largest single group of tissue-feeding experiments in this investigation was that involving the administration of incubated livers to ducks. Forty-three individual experiments of this character were performed, in which 93 birds were used, mainly pintails and mallards. In 14 of the 43 experiments no toxicity was demonstrated, negative results usually being associated with certain lots of incubated liver in which apparently the *botulinum* toxin had not developed. Among the others the results varied from cases of rapid intoxication, with death following in less than 6 hours after ingestion of the toxin, to sublethal cases, in which all typical symptoms were revealed, followed in due course by complete recovery.

The degree and rapidity of intoxication conformed closely to the size of the dose. This was well illustrated in one experiment in which five female mallards of nearly equal weight were given oral doses of toxic liver of 1, 2, 3, 4, and 5 g, respectively. Although all the cases resulted fatally and the onset of symptoms was rapid, they were graduated in intensity almost in direct proportion to the quantity of toxin ingested. Comparable reactions were detected when equal doses were fed to birds of different body weights.

That internal organs, other than livers, of birds dying of the disease may become the source of toxin when properly incubated was brought out in experiments in which typical duck-sickness symptoms were produced by the feeding of incubated kidneys. In

one of two experiments positive results were obtained also by the use of the incubated blood of birds that died of the disease.

With an equal degree of uniformity the syndrome of duck sickness was produced by the intraperitoneal injection of saline-solution extracts of toxic tissues. In this procedure a small quantity, usually 1 to 3 g of minced toxic tissue, was agitated in a somewhat greater volume (5 to 10 cc) of saline solution and allowed to settle, after which the supernatant liquid was further diluted to reduce the concentration to a point where the small doses needed for injection could be conveniently measured. By this means the susceptibility of certain birds, highly refractory to oral doses, was demonstrated (pp. 44 to 45). The results with gulls were of particular interest, since these birds develop certain peculiarities of syndrome that aid in revealing the similarity of the disease produced in the laboratory with that found in the field. Further confirmation of the identity of the experimentally produced disease came to light on many occasions in later work (1931–32), when standard cultures and filtered toxin, originating from material associated with the disease in the field, took the place of incubated body tissues or their extracts.

The clinical picture of this experimentally produced disease, as well as that of duck sickness in the field, is similar to that of avian botulism as it has been recorded in literature. Opportunity to make comparisons with the syndrome produced by the toxin of known type C botulism was afforded in numerous experiments involving both ducks and pigeons. Ofttimes sick birds from the field, those made sick with cultures originating from field sources, and those inoculated with known type C botulism were on hand at the same time.

### RECOVERY OF THE ORGANISM

Recovery of *Clostridium botulinum*, type C, from the internal organs of a bird that has died of duck sickness is not generally looked upon as having diagnostic significance. This is particularly the case when recovery is from a point in the alimentary tract, which often may contain a few spores or vegetative forms which, under these conditions, are harmless and possess nothing of pathogenic importance. Gunderson has shown that in a series of 10 pigeons fed lethal doses of type C culture, 8 revealed the presence of the organism in the liver, which had been removed aseptically immediately after death. The internal organs (mainly livers) of a series of ducks, geese, and shore birds that had died of duck sickness in the Klamath Falls district and in other disease-infected areas of the West disclosed type C *botulinum* in 62.9 percent of the samples.

In distinction from this relatively high frequency of recovery from the tissues of birds dying of the disease is the infrequency of the organism in the tissues of birds dying from causes other than botulism. Gunderson has demonstrated that the cultured livers of 20 unaffected pigeons failed to disclose the organism in a single instance. In commenting on his examination of ducks that had died of lead poisoning in Minnesota, he reports that in a series of cultures of 34 birds, only 1 (2.9 percent) revealed type C.

It is of more than ordinary interest to note that type A has been recovered from the livers of ducks dying of lead poisoning (2 cases) and from the liver of an apparently healthy ruffed grouse (1 case).

Hobmaier (*40, p. 14*) likewise has stated that he has demonstrated the causative organism of duck sickness in the livers of 22 of 24 birds dying of the disease, whereas "47 investigations of birds not having suffered from the sickness failed to show this organism."

The initial determination of *Clostridium botulinum*, type C, from tissues of birds dying of duck sickness was made by Giltner as early as October 3, 1930. At that time the organism was detected in the internal organs (mainly the livers) of wild mallards, pintails, and ring-billed gulls, as well as in mud from Tule Lake. Since that time the organism has been recovered from the internal organs of a number of other wild species. Later Giltner found it in the liver of a juvenile prairie falcon, collected at Tule Lake, and in the work conducted at Klamath Falls, it was recovered by Gunderson from the tissues of the following species: Canada goose, green-winged teal, coot, long-billed dowitcher, western sandpiper, avocet, northern phalarope, California gull, and Bonaparte's gull.

In addition to the material gathered in the Klamath Falls-Tule Lake area, *Clostridium botulinum*, type C, has been identified in the internal organs of wild birds collected on the Bear River marshes, Great Salt Lake, Utah; American Falls Reservoir, Idaho; Colusa, in the Sacramento Valley of California; the mouth of the New River at the south end of the Salton Sea, Calif.; Cone, Tex.; Antioch, Nebr.; Antelope Lake, Clark County, S.Dak.; and Windom, Cottonwood County, Minn.

Such circumstantial yet significant bacterial evidence, gathered from widely scattered areas of infection, adds weight to the already well-established hypothesis that duck sickness is the same throughout its range.

The causative organism has been found in many media other than the bodies of birds dying of the disease. Though this has no significance from a diagnostic standpoint, it gives an idea as to the location of the organism in the field. Positive results were obtained on numerous occasions with soil or mud on duck-sickness areas. Often such material was heavily laden with miscellaneous organic matter, including strands of filamentous algae, masses of living and dead *Lemna*, copepods, snails, and insects. Debris from the Bear River flats, composed almost entirely of insect remains, disclosed the organism. Likewise it was found in both the larvae and pupae of hydrophilid beetles, the cocoons of which studded the surface of the dense algal beds at Tule Lake. Colonies of copepods, sarcophagid larvae (dead and alive) found on or near the bodies of dead birds, and even water obtained from the vicinity of such materials disclosed the organism. In Minnesota, Gunderson found the causative organism in dead and living snails. At Tule Lake wheat heads of the season's crop, as well as barley and mixed grain (chick feed), when submerged for a time in the water of infected environments, frequently yielded *Clostridium botulinum*. At the mouth of Bear River the decaying tubers of bayonet grass (*Scirpus paludosus*) harbored the organism.

In a series of 96 cultures inoculated with material from various media collected in duck-sickness areas at several points in Western States, Gunderson has detected type C *botulinum* in 45.8 percent. The contaminating material was divided about equally between mud,

water, and shore debris on the one hand and various items of bird food on the other.

In studying the prevalence of the causative organism in the field Hobmaier (*40, p. 14*) has demonstrated its presence in 28 of 76 mud samples collected in suspected areas. He records it also in 2 of 8 samples of foam collected from the surface of ponds.

### DEMONSTRATION OF TOXIN IN THE FIELD

After the syndrome of botulism had been reproduced by feeding or injecting toxic material originating from tissues of birds that had died of the disease, and after the type C *botulinum* had been recovered from numerous samples of pertinent material, there still remained, at the outset of studies in 1931, the necessity of demonstrating the presence, in the field, of preformed toxin in or associated with food items or water that might be ingested by birds. This was accomplished in more than a score of instances, thus completing the etiological picture in the demonstration of botulism as the cause of duck sickness.

To Gunderson is to be credited much of the success in this phase of the study. The technic employed involved direct intraperitoneal injection into pigeons of 0.5-cc doses when the medium was fluid. From more nearly solid media, toxin was first extracted with a normal saline solution, which was then injected. In no case, however, was there any preliminary incubation or culturing. Whenever toxicity was demonstrated and botulism was indicated, the type involved was determined by adequate toxin-antitoxin tests. It may be explained that in all material gathered in the Klamath Falls district only the type C *botulinum* was disclosed.

Gunderson has demonstrated that of 76 samples of suspected material collected in sickness areas at Tule Lake 22, or nearly 29 percent, disclosed the presence of *botulinum* toxin. In seeking for toxin in the field, search was directed first to the carcasses of birds that had died of the disease and in such media toxin demonstration was not difficult. This was accomplished usually with bodies found lying on exposed flats, but the process was aided at times by encircling submerged bodies with metal cylinders to prevent undue dispersal of toxin by water movement. Toxin of type C botulism has been so demonstrated in the bodies of western sandpipers, avocets, coots, pintails, and green-winged teal. It likewise has been revealed in solution in shallow water adjacent to such bodies.

The larvae of sarcophagid flies feeding on infected carcasses die in great numbers when unable to find places sufficiently dry for pupation. These larvae were shown to be the source of a potent toxin, even when wind and water action had carried them considerable distances from the place where they were reared. Such material easily may become an intoxicating food item for shore birds and ducks.

Even living sarcophagid larvae may be toxic, as was demonstrated in one experiment, in which 15 were removed from the body of a green-winged teal and fed to a healthy bird of the same species. This bird later developed typical duck-sickness symptoms and died 6 days after ingestion of the larvae.

Toxin associated with dead sarcophagid larvae was revealed in several experiments in which the liquid from crushed larvae or that

filtered from masses of them was injected into pigeons. Typical of these is one in which 0.5 cc of liquid derived from dead maggots, which had floated some distance away from the body of an avocet, where they were reared, killed a domestic pigeon in less than 24 hours after a direct intraperitoneal injection. Circumstantial evidence of the contraction of duck sickness by the ingestion of sarcophagid larvae under field conditions was brought to light through the stomach examination of afflicted birds. Both the senior author and Sperry have found the remains of a score or more of these larvae in the stomachs of sick green-winged teal at Tule Lake.

Mud on which a dead duck had lain, but from which it had been removed, retained toxin in substantial quantities for 17 days. This was demonstrated in an experiment in which 0.5 cc of a saline extract of this mud, when injected, killed a pigeon in less than 48 hours.

Toxin also was demonstrated in barley scattered in shallow water and on mud flats in infected areas. Liquid drained from such masses of grain as had lain exposed for a week proved lethal to a pigeon on intraperitoneal injection of a 1-cc dose.

The possibility of toxin production in natural media was further demonstrated by the incubation in the laboratory of material that was obtained from field sources. A mixed lot of insect debris associated with *Lemna*, algae, copepods, and snails produced toxin during an incubating period of 5 days. Relatively potent toxin was produced in the laboratory in grain that had been inoculated with the type C *botulinum* and submerged for 2 weeks in water, which, at the start, was highly alkaline. Such a reaction may explain the sudden outbreaks of duck sickness that at times occur on artificial ducking grounds where shallow-water areas are heavily baited.

The apparent toxicity of scattered grain also was revealed by field observations. On two occasions (late in August and early in September 1931) a marked increase in sick ducks was noted on overflowed areas east of Tule Lake several days after these had been baited heavily with barley. This was done with the definite idea of demonstrating the potential danger from submerged grain in infected areas. The toxin-producing properties of grain also were revealed in experiments in which mixed grains in open-top glass jars were submerged on infected mud flats and allowed to incubate for a week or more.

Hobmaier has indicated the toxin-producing possibilities of other natural media when properly incubated. These include beetles, grasshoppers, and the bodies of fish (*40, p. 13*).[14]

In view of the high percentage of recovery noted among wild birds that contract this disease under field conditions, it would appear that the quantity of toxin ingested is either small or its potency low. Gunderson has pointed out that, as a rule, there is an appreciable interval between seizure and death among wild birds, which indicates a relatively small dose. It is possible, as he has also suggested, that the ultimate intoxication may be the result of several additive doses no one of which would have affected the bird.

[14] Mention is also made of additional substantiating evidence disclosed in California by Hobmaier (*40*), who has demonstrated the presence of toxin of type C botulism in the blood stream of sick birds. This was accomplished by inoculating mice, by which means extremely small quantities of toxin are demonstrated.

### SUMMARY OF EVIDENCE OF BOTULISM

1. The clinical picture of duck sickness, both with respect to symptoms and pathology, is identical with that produced in experimental birds that have ingested the toxin of pure cultures of type C *botulinum*.

2. The causative organism has been recovered not only from the tissues of birds dying of the disease but also from soil and other material collected in infected environments. Though the former does not carry with it certain diagnosis, it is significant that the organism is frequently present in the tissues of sick birds and absent from those that are healthy.

3. The demonstration of the toxin of type C *botulinum* in food and water commonly ingested by wild birds points to the channel through which the malady is contracted. This study has revealed toxin under field conditions in such bird-food items as sarcophagid-fly larvae and miscellaneous insect debris (attractive to shore birds and ducks), submerged grain (eagerly sought by ducks), and bodies of birds that have died from the disease (a common food source for gulls and magpies). The fact that mud of infected areas rich in decaying organic matter also has been shown to be toxic may account for much of the mortality of puddling ducks and probing shore birds. Toxin demonstrated in the water of small pools is a source of danger to any birds that may come in direct contact with it.

4. The incidence, course, and disappearance of duck sickness in the field, conform to the influences of temperature and environmental factors in a highly suggestive manner. In other words the epizootiology of duck sickness is just what one would expect in an outbreak of botulism among wild fowl.

## FACTORS RESPONSIBLE FOR DUCK SICKNESS OR INFLUENCING ITS DISTRIBUTION

Since duck sickness (botulism) is an intoxication, and not an infectious disease, it is contracted by wild fowl only through ingestion of toxin preformed in suitable media. For this reason the malady has its basis not so much in any inferior or predisposing condition of the bird as in factors affecting the welfare of a micro-organism living apart from it. These factors include such things as (1) prevalence of dead organic matter, (2) degree of alkalinity or salinity, (3) temperature, (4) water level and water movement, and (5) when the malady appears in epizootic intensity, an abundance of birds obtaining food or water in infected areas. It is a favorable aggregate of these factors that makes of duck sickness a seasonal malady reaching its peak late in August or early in September. It is the unfavorable reaction of one or more of these factors that may cause irregularity or even total absence of the disease in certain years, even though the organism itself may be abundantly present.

### PRESENCE OF THE CAUSATIVE ORGANISM

The presence of the specific organism *Clostridium botulinum*, type C, is a prerequisite to the incidence of duck sickness in any locality. That it is widely distributed in the United States and is especially

abundant in areas where the disease has once occurred, there is little doubt. Meyer and Dubovsky (*47*) in the course of their studies of the prevalence of the human types A and B in this country encountered nontypical forms, some of which may have been the type C of Bengtson. Graham and Boughton (*26*) have recorded the organism at several points in Illinois, and Bengtson (*3*) has reported it in material from Missouri, Oklahoma, Illinois, and Maryland. This investigation has demonstrated its presence in such widely scattered areas as southern Oregon, northern and extreme southern California, the Salt Lake Valley, Utah, the Panhandle of Texas, western Nebraska, southwestern Minnesota, and the vicinity of Washington, D.C.

In the course of the study in Oregon and California Gunderson recovered the organism from 47.3 percent of 55 samples of mud, shore debris, and other material not generally looked upon as bird food. It was present in 44 percent of the 41 samples of material more or less intimately associated with bird food. In each instance the material was collected in a duck-sickness area.

In the course of later work in Minnesota, Gunderson recovered the type C organism from 4 of 11 samples collected in a duck-sickness area near Windom. This material included 2 lots of snails, 1 of maggots, and 1 of mud. In 99 samples from areas free of sickness, however, type C was disclosed only once and type A twice. In a study of 76 mud samples collected in supposedly infected areas in the Sacramento and Imperial Valleys during 1931, Hobmaier determined the presence of type C *botulinum* in 28 (*40, p. 14*).

The causative organism of duck sickness is now so prevalent and well established in the main centers of duck sickness that no theory of invading pollution is needed to explain any specific outbreak at these points. Its presence may be admitted, and the outbreaks explained on the basis of temporary conditions favorable to its growth and production of toxin.

### PREVALENCE OF DEAD ORGANIC MATTER

Dead organic matter is necessary for growth and toxin elaboration by the causative organism of duck sickness. Such material is present in a great variety of forms in every marsh or mud flat area and on overflowed lands. Remains of insects, entomostracans of many kinds, mollusks, and even vertebrates (pl. 5, A) serve as excellent media for development of the organism. In one outbreak of botulism among captive ducks in South Africa, the bodies of earthworms were suspected of being the source (*56*). As brought out by this investigation, submerged grain and possibly other dead vegetable material may act as added sources of toxin, closely associated with attractive food items. Even finely divided and commingled particles of animal and vegetable matter found in the ooze beneath shallow water or on mud flats apparently play an important part in the intoxication of such birds as ducks and shore birds, whose puddling and probing for food throw them in direct contact with any toxin there formed. The peak of duck-sickness outbreaks coincides in general with the seasonal period of organic decay. Without this bacterial food supply the disease cannot gain headway, as

evidenced by the absence of duck sickness in waters overlying clean, sandy bottoms. This fact has served as the basis of the most effective remedial measure against the malady—the elimination of extensive mud-flat areas by proper water control (p. 73 to 74).

### DEGREE OF ALKALINITY AND SALINITY

While much is yet to be learned concerning the effect of alkalinity on the growth and toxin production of *Clostridium botulinum*, type C, under field conditions (pl. 5, *B*) and possibly even on its distribution, there is no doubt concerning its important influence in laboratory experiments. Gunderson, citing other workers in this field, has called attention to the fact that the optimum range of hydrogen-ion concentration for growth and toxin production lies on the alkaline side of the scale. Bengtson (*3*) has stated that the medium should have a pH reaction of 8.0 to 8.5 for proteolytic and 7.0 to 7.5 for nonproteolytic strains of *C. botulinum* to insure the production of potent toxin.

By direct experimentation with a limited number of birds Gunderson has shown the favorable effect of alkalinity on the rate of toxin production by organisms originating from cases of duck sickness, and in later laboratory work he adopted a technic that guaranteed a definite alkaline reaction.

> In making the media, the formula of Bengtson (one part of chopped beef and two parts of water) was altered by substituting for the water a beef broth having a pH of 8.0, after which 10 grams of peptone were added per liter. Furthermore, a half-inch layer of calcium carbonate was placed in the bottoms of the culture tubes before the medium was introduced. The pH was greater than 8.0.

A condition of alkalinity prevailed in all waters directly connected with duck-sickness outbreaks that were investigated. This varied from a minimum pH reading of 7.1 (at Cone, Tex.) to a maximum in excess of 10.0 (in the Klamath Falls district), with an average of 8.5 based on 15 samples. A pH value in excess of 9.6 has been recorded for the open water of Tule Lake, although a reading of 9.4 or 9.2 is usual for the shallow water closer to areas of bacterial action on the shore. On the mud flats and in places where organic decay was manifest, the pH was lowered to 8.8 or less. It was quite apparent that the alkalinity of the lake itself was exerting a constant and pronounced neutralizing effect on the acidity resulting from bacterial action.

Gunderson also has called attention to the fact that—

> an alkaline pH, alkaline inorganic buffers, and a high concentration of various salts may partially sterilize the soil to the disadvantage of competing organisms, leaving the field to *Clostridium botulinum*.

It is also well established that despite the favorable reaction of a certain degree of alkalinity on bacterial growth and toxin production, continued or increased alkalinity or salinity has a destructive effect on preformed toxin. Thus, sick birds are not found in the immediate environment of highly saline waters, particularly at Great Salt Lake. That part of the shore line of this lake in direct contact with water having a saline concentration of about 20 percent has been free of sick birds, while the relatively fresh-water marshes at the mouths of affluent rivers were the scenes of disastrous out-

breaks. A similar condition exists at the Salton Sea, where sickness occurs, not in the highly saline environment of the open sea, but in the marshes and mud flats created near the mouths of the New and Alamo Rivers. Likewise Mono and Owens Lakes, Calif., whose chlorine-carbonate waters contain saline concentrations varying from 7 to 20 percent (*9, p. 162*), appear to be free of duck sickness, although they may harbor birds in goodly numbers.[15]

Duck sickness in epizootic proportions never has been reported on tidal flats washed by waters whose saline content approached that of the ocean (35,000 p.p.m.).[16]

In areas of highest salinity, the absence of duck sickness has always been a challenge to the validity of the theory of alkali toxicity. Under the new concept of duck sickness, this same challenge awaits explanation. For answer, one now looks to the bacteriological aspects.

Throughout the history of research in human botulism, beginning with the initial work of van Ermengem in Europe, the matter of growth-inhibiting or toxin-destroying agencies or reagents has been noted. Although most experimental work has been done with the human strains A and B, with the primary objective of preventing or curtailing toxin production in preserved foods, the results attained are signficant, particularly when considered in connection with certain experiments of this investigation.

Van Ermengem himself, while working with what today is considered to have been type B, found that growth of the organism was inhibited in a medium containing 6 percent of sodium chloride (*19, 20*). Dozier (*17, p. 155*) found that "No strain of *B. botulinus* cultured gave any evidence of growth in double-strength veal infusion containing more than 8 percent of NaCl." Bidault (*4*) showed that 3 percent solutions of sodium chloride, potassium chloride, calcium chloride, and magnesium chloride nullified the toxin of type B and reduced the potency of type A. When a concentration of 6 percent of these salts was used, growth was completely inhibited. Thom, Edmondson, and Giltner (*67*), working on type A, found that toxin was produced in the presence of 5 percent but not 8 percent of sodium chloride. Wyant and Normington (*73*) found a somewhat greater tolerance to sodium chloride on the part of types with which they experimented. It is evident, however, that sodium chloride and certain other salts in concentrations as great as that of sea water tend to be unfavorable to the growth of types A and B.

Of even greater significance is the action of distinctlv alkaline salts on preformed toxin. Here again the pioneer, van Ermengem, has pointed out that sodium carbonate—

> in the proportion of 0.5, 1, and 3 per cent, . . . when allowed to act on the toxin for 24 to 48 hours, rendered it innocuous to rabbits. . . . A solution of pure toxin in water was rendered instantly inert when an equal volume of 3 percent sodium carbonate was added (*3, p. 62*).

[15] An earlier report of bird mortality at Owens Lake (*22*), considered to have been duck sickness (*71*), was not, of course, substantiated by bacteriological evidence. It probably should be charged either to a lack of suitable food supply for birds that had just completed a long migration flight, or to direct saline intoxication.

[16] A possible case of botulism reported among shore birds on an island in Massachusetts Bay (*1*) may have had its origin in toxin produced in the carcasses of stranded blackfish (*Globicephala*) and a seal (*Phoca*), the bodies of which had been washed above high tide and therefore were out of direct contact with salt water (pp. 30–31).

B35603 B35620

*A*, Decaying bodies of birds that have died of duck sickness become additional centers of infection. *B*, Crystaline deposits on shore-line debris—alkaline salts that play an important role in the bacterial processes producing the toxin of botulism.

B34155 B5025M

*A*, Field laboratory at Klamath Falls, Oreg., the scene of the Biological Survey's research work in 1929, 1930, and 1931. Nearby were pens for experimental and convalescing birds. *B*, Rescuing affected birds, a means of saving many victims that otherwise would die on the mud flats.

Other research workers also have demonstrated that the potency of preformed toxin is perceptibly reduced by an increase in alkalinity.

The toxin-destroying property of sodium carbonate was made the subject of experiments in this investigation involving both the feeding and injection of toxic material that had been subjected to the action of the carbonate (or in some cases, the bicarbonate) for variable periods. A 6-hour contact between a toxic extract and a 3-percent sodium carbonate solution completely nullified the toxin, and even a 1-percent solution in contact for 67 hours appreciably reduced its potency. A 0.5-percent solution, however, failed to effect a material loss in potency. With the bicarbonate of soda a certain retarding of toxic action was noted in one experiment, in which a 3-percent solution was in contact with the toxin for 24 hours.

In the light of this and other experimental work and the previously reported results attained by others with the chloride, it is of interest to note again the chemical composition of the waters of those lakes in which duck sickness has not been reported. Great Salt Lake (on the open waters of which the malady does not occur) has a sodium chloride content that fluctuates above and below 20 percent, depending on the depth of the lake; that of the Salton Sea (where the disease likewise is confined to contiguous, relatively fresh-water areas) is close to 3.5 percent (*10*). Sodium carbonate and sodium chloride form most of the 51,170 parts per million of total salts of the water of Mono Lake (*9, p. 162*), as they also do in the even more highly saline water of Owens Lake.

Although further evidence is needed, the foregoing indicates that in certain highly saline waters the absence of duck sickness may be due to a bacteriological factor—inability of *Clostridium botulinum* to thrive, or its toxin to persist, in the presence of high concentrations of certain salts. Even lower concentrations may be equally effective when the action is continuous. A seemingly anomalous situation is presented: Alkalinity in a pH sense is looked upon as a prerequisite or at least a most favorable condition for the growth of the causative organism and the evolvement of its toxin; yet, alkaline salts, in high concentrations, may reduce or completely destroy preformed toxin.

In view of the general conformity of the range of duck sickness to that of the region of alkaline waters in the United States (fig. 1); in view of the known favorable action of moderate alkalinity on the production of *botulinum* toxin; of the apparent buffering action of bodies of alkaline water on the acidity arising from bacterial action in decaying organic matter on shore lines or on mud flats; and in view of the possibility of such alkalinity destroying organisms competing with *Clostridium botulinum*, it would appear that moderate alkalinity is favorable to the type C organism and possibly a prerequisite to the epizootics among wild fowl. Furthermore, the deleterious effect of excessive alkalinity or salinity on the growth of this organism and on its toxin, facts recognized in the laboratory and indicated in the field by the absence of the disease in certain highly saline waters, points to a limiting factor worthy of mention. Alkalinity, therefore, may be a determining factor in the incidence of duck sickness in epizootic form.

### TEMPERATURE

Temperature also plays an important part in the incidence of duck sickness, since it not only strongly affects the extent of toxin production by *Clostridium botulinum* but also influences the general processes of decay. These involve other bacteria, which, by reason of their consumption of oxygen, may aid greatly the growth of the anaerobic *Clostridium*. Although there is a wide range of temperature in which toxin may be evolved, Gunnison and Coleman have stated that the optimum for the growth of type C *botulinum* is 37° C. (98.5° F.) (*29*).

In general, the disease coincides with or immediately follows periods of hot weather. Lack of exact synchrony is to be expected, since various factors other than temperature control the incidence of the disease. Furthermore records based on atmospheric temperature are not always proper criteria on which to judge conditions where toxin is being produced. Beneath mud or water surfaces daily-temperature ranges are less extreme, and there one will find a seasonal variation that reaches a maximum in August and September, the period when outbreaks of duck sickness usually reach the peak. Ofttimes duck sickness stops rather suddenly when the temperature drops late in September or early in October. This, however, frequently may be due to the influx of irrigation water, or a change of bird movements with the advent of cooler weather, or to other attendant factors. As a rule outbreaks in central or southern California extend later into the fall than those in Oregon or Utah, and in the San Joaquin Valley in certain seasons the disease has persisted until December and January. The disastrous outbreak on the Bear River marshes in 1932, however, was severe late in October, and sick birds still could be found when ice had begun to form after the middle of November.

### WATER LEVEL AND WATER MOVEMENT

Except for the requisite of ample organic matter for toxin production, no single factor enters more strongly into the etiology of duck sickness than the matter of water level and water movement. Even the less observant have noted that duck sickness is intimately correlated with areas of shallow, stagnant water and mud flats. Nothing will put an end to an outbreak more abruptly than a perceptible deepening of the water or a flushing of the infected area by heavy rains. Likewise, where water depths of a foot or more are maintained, the disease is seldom in epizootic form.

In the light of the present concept of duck sickness the reasons for such reactions are obvious. In the first place, deep water not only tends to keep temperatures down and thus retard toxin production, but the quantity of suitable media in the form of dead animal and vegetable matter will be less on deep bottoms than in shallow water or on shore lines, where the remains of surface life may be segregated en masse by wind and wave action. Likewise *botulinum* toxin is soluble and readily taken up, diluted, and dispersed by a large volume or movement of water. Furthermore, aquatic bird life, both shore birds and waterfowl, are particularly partial to shallow-water and mud-flat areas, where when not disturbed, they spend many hours in probing or puddling for food or just loafing and resting.

Circumstantial evidence of the important role played by shallow water is to be found in the relative infrequency of duck sickness among deep-water ducks, particularly canvasbacks, scaups, and ruddy ducks. Young redheads, however, do succumb in considerable numbers late in summer, when they feed extensively in shallow water, as also do pintails and mallards. Some mortality among diving ducks in spring has at times been charged to duck sickness. This has occurred in the Klamath Falls district as well as at Great Salt Lake, but the principal evidence as to identity is an apparent similarity of symptoms. There is the possibility that these deep-water feeders may reach spots of toxin elaborated during the previous season but not available to the shallow-water species.

Observations in the Klamath Falls district brought out the fact that duck sickness is by no means confined to conditions brought about by a recession or an evaporation of water. An equally dangerous state of affairs may arise from the creation of shallow-water or mud-flat areas by a slight rise or extension of water surface. The severe outbreak of 1925 at Tule Lake occurred after a marked rise in water, which submerged surrounding grainfields. In 1929 an area of infection was caused by the breaking of a low dike at the northwest corner of the lake, the water overflowing to adjacent wheat stubble. In 1930 and 1931 a slow rise in the water of the lake itself again produced extensive mud flats and shallow water to the east.

The influence of water level on the incidence of duck sickness also has been illustrated by the history of events at Great Salt Lake. The terrain immediately surrounding the lake is flat and, in years when the lake is high, the inflowing waters of the Bear River spread over wide areas. This happened in 1910, causing the most disastrous outbreak of record. Botulism in varied intensity followed a somewhat lowered lake level during the years immediately following. The next year of extensive mortality was 1921, when the seasonal peak of the lake level was fully a foot lower than in 1910, yet it was higher than in either of the two preceding years. From 1921 to 1931 some duck sickness occurred practically every year, but in 1929 a severe but short-lived outbreak in the immediate vicinity of the mouth of the Bear River ran its course at a time when the lake was relatively low but at a level that made this local area a stagnant mud flat. In December 1931, for the first time since 1907, Great Salt Lake dropped to the zero level of the Midlake gage, making the water in the area known as Willard Spur extremely shallow. In the summer and fall of 1932, wind action drove this shallow water over extensive flats, and a most disastrous outbreak of botulism followed (p. 34; pl. 1, *B*).

Incidents such as this, in which outbreaks of marked severity appear on newly flooded land that has been dry during periods of hot weather, lead to the surmise that, even though these lands may have been dry on the surface, conditions beneath may have been favorable to toxin production. With warmth, moisture, suitable organic matter, an alkaline environment, and a relatively anaerobic condition, subsurface toxin production might easily take place. The absence of flood water would tend to prevent toxin dispersal and dilution, and, when these areas are eventually submerged, the preformed toxin becomes readily accessible to puddling ducks.

### ABUNDANCE OF BIRDS

An abundance of birds is a necessary corollary of a pronounced epizootic of duck sickness under natural conditions. Occasionally the infection becomes so intense in local spots that concentrated flocks may lose most of their numbers. Ordinarily, however, only a relatively small proportion of the birds frequenting a toxic area contract the malady. This would indicate that spots of toxin sufficiently potent to affect birds are probably very local.

Such a condition was demonstrated on overflowed land east of Tule Lake in 1930 and 1931. There, during August and September, a shallow-water area several square miles in extent cut by several low dikes was a constant attraction to a mixed flock of birds, mainly coots, pintails, mallards, cinnamon and green-winged teals, and Canada geese. Every morning this heterogeneous flock of 4,000 to 6,000 could be found in its customary place, feeding or loafing on the low dikes. A search over a circuitous route of about 2 miles would reveal about 20 sick birds. A similar search on the following day would reveal possibly only 8 or 10 newly sick birds; if the search were delayed a day or two an increase in the number of the newly sick and dead would be noted, but seldom was this number more than 25, representing about 1 out of every 200 birds present.

When large numbers of sick and dead birds are found during severe outbreaks, the mortality may represent the accumulated losses to successive migratory flights or feeding flocks that enter the locality unobserved at night. Although bodies of the dead rapidly disintegrate on the hot flats, marked evidence of the mortality may remain 10 days, 2 weeks, or even longer. Consequently to appraise adequately the significance of a large number of dead, one must consider the bird population that has previously frequented the area.

## REMEDIAL MEASURES

Having learned the cause of a malady, the inquiry naturally follows: What can be done about it? In the case of duck sickness the efficacy of certain remedial measures had been demonstrated long before the actual cause had been ascertained. Though the reasons for the relief attained were misunderstood, there was ample demonstration of the usefulness of the methods then employed.

Remedial measures include both direct treatment and prevention. Under the former will be discussed the utility of antitoxin and other therapeutics as well as the benefits to be derived from rescue work and the so-called "fresh water" treatment. Under prevention will be considered procedures involving (1) deep flooding or drying of sickness areas; (2) employment of frightening measures to drive birds out of known infected areas; and (3) decrease of infection and toxin production by sanitation, including proper carcass disposal.

### TREATMENT OF BIRDS

#### ANTITOXIN

An antitoxin against type C botulism has been developed by methods ordinarily employed in the production of antiserums. Goats or horses that have been immunized by the administration of toxin in small doses over long periods are the usual sources of antitoxins.

Injected in proper doses, simultaneously with or soon after the ingestion of toxin, such antitoxins protect the bird or other animals treated.

Little if anything, however, of practical value can be expected from the use of antitoxin as a combative measure against any malady of wild ducks. Although research workers in the field of botulism have shown that antitoxin administered to experimental animals even after symptoms have developed possesses some slight therapeutic value (*3, p. 83*), such animals cannot be saved if the antitoxin treatment is delayed until the symptoms are well advanced (*6*). A wild bird so incapacitated by duck sickness as to permit its capture for treatment would have ingested the toxin hours or even days previously, and hence would be at a disadvantage in an attempt to cure by means of antitoxin.

That several contacts with duck sickness fail to set up an immunity in wild ducks also argues against the possibility of ever developing any practical prophylactic treatment with antitoxin. It could hardly be expected that artificially induced immunity would endure over long periods or to a degree that would cope with the superlethal doses often ingested.

A pronounced tolerance for the toxin of *Clostridium botulinum*, however, may be encountered now and then in individual wild birds used for experimental purposes. A case in point, of which there were several in the course of these studies, was that of a pintail, which had assimilated two successive oral doses of 0.2 g of toxic material without manifesting symptoms, whereas a 0.1-g dose ordinarily produced a typical case of duck sickness.

#### RESCUE OF AFFECTED BIRDS

Next to such preventive measures as elimination of extensive infected areas or driving the birds from them, the rescue and subsequent care of affected birds probably has yielded the greatest returns in the battle against duck sickness. A high percentage of the birds rescued (pl. 6, *B*) and brought into pens where they can be given direct attention, recover. Experimental evidence, however, is still insufficient to indicate the extent that birds recover under natural conditions; and, therefore, despite the gratifying results attained in rescue operations, the real value of such work is uncertain. The mortality is the result of the combined effects of the toxin of botulism and various other attendant factors to which the helpless birds are exposed in nature, including the devastating heat of mid-day, attacks of predators, feather-soaking, chilling at night, and even drowning. When these dangers are minimized or eliminated, as is the case with rescued birds, a greater degree of recovery can be expected, and it is on this basis that rescue operations may be advocated.

In the course of his work at Great Salt Lake, Wetmore (*71*) kept records of the results attained in rescue operations, involving 1,211 ducks of 7 species. Of these, 284 died and 927 recovered. After making allowance for a large number of very sick birds, which, except for experimental purposes, would not have been brought in for treatment, Wetmore concluded that the ratio of recovery would be about 90 percent of the birds rescued. The results, when tabulated (including all birds rescued), indicated that of the three species most

often affected, the green-winged teal showed the lowest degree of recovery (75 percent), the pintail next (77 percent), and the mallard the greatest (81 percent).

The percentage of recovered birds was somewhat lower at Tule Lake than at Great Salt Lake. A number of factors accounted for this. In the first place, rescue work at Tule Lake was for experimental purposes and not with the primary objective of salvaging birds. In addition, the birds had to be transported 30 to 45 miles by automobile to the experimental pens. Even with the greatest of care many died during these trips.

Details of rescue methods often have to be worked out to meet local conditions. At Great Salt Lake, where travel on some of the extensive mud flats is extremely arduous, transportation problems have been met in part by the use of narrow, flat-bottomed boats of shallow draft, having paddle wheels driven by a gasoline engine. This peculiar but efficient type of boat, passing under the local name of "mud queen", can be operated in very shallow water and used to tow one or more even shallower-draft boats for transporting the sick ducks. At Tule Lake conditions for capturing sick birds were more favorable, since, with the exception of a few areas, the bottom was fairly firm and in 1929 and 1930 the water depth was such that nearly the whole lake could be traversed on foot. In those seasons a rubber boat or light skiff, pulled along by hand, was used to gather the sick birds.

At Lake Malheur, however, in 1929 the difficulties of rescue work were greater. Water levels were so low that navigation in any kind of boat was slow and arduous and progress on foot was prevented by the almost fathomless mud. Under such conditions rescue work could cover nothing more than the main channels of deeper water. At other points, as in some areas adjacent to the Salton Sea and on the grounds of certain duck clubs elsewhere in California, best progress in rescue work was made simply by searching the borders of levee banks, where wind and wave action had drifted the helpless birds. These could be gathered and placed in a light skiff pulled along in the deeper water of the adjacent borrow pit.

In gathering sick ducks on open-lake or mud-flat areas two or three men can work to advantage in loading a single boat. When the birds are widely scattered and the flats can be traversed on foot the men can best bring small lots to the boat by placing the birds in loosely woven burlap or netting sacks, or in baskets. When they are transferred to the boat, or "duck ambulance", the larger species should be separated from the smaller, and the vigorous from those that are prostrate.

The question often arises as to whether one should endeavor to rescue all sick birds encountered, regardless of their degree of disability. The answer depends upon the facilities for transportation and subsequent care. If conditions affecting rescue work are favorable throughout, no bird found alive need be overlooked. Under conditions adverse for handling, birds that are utterly prostrate may as well be left and efforts confined to those less seriously affected. Birds still active should not be passed by on the assumption that they are not seriously affected or are on the road to recovery, as exactly the opposite may be the case.

When there are many rescued birds so active that they can readily scramble out of an ordinary boat, their escape can be prevented by draping a fish seine or other netting over the top and fastening it at intervals. A few rushes or similar vegetation strewn lightly over the birds will afford protection from the direct rays of the sun and instill in the more restless ones a sense of security, thus reducing their desire to escape. Frequently a piece of light burlap thrown over particularly active birds will induce them to remain perfectly quiet. In transporting shore birds, particularly sandpipers, phalaropes, and other smaller species, pasteboard cartons are useful. These may be set in the bottom of the boat and the cover loosely closed to prevent the escape of active individuals.

Success in rescue work depends on the care given the birds at the recovery pens. A number of pens should be provided so that birds varying greatly in size or in degree of disability may be kept separate. Under some conditions it is an advantage to have portable cages. For small-scale operations, involving the salvage of a few hundred, it is convenient to have the floor size no greater than 6 by 12 feet, and the height 4 or 5 feet; the frame well constructed but light, and covered on the sides and top with 2-inch-mesh poultry wire. A 12-inch baseboard, forming the lower part of the frame, will reduce the danger of ducks injuring themselves by trying to escape through the wire. When it is planned to rescue thousands of birds, as has been done at Great Salt Lake, cages of larger dimensions, especially for the less severely affected or the nearly recovered birds, are more economical. One or more of these cages (depending on the number of birds being salvaged) should be so placed that part of the cage will stand in water or at least that an adequate water supply will be constantly available. In placing cages, stagnant water should be scrupulously avoided. Other cages, in which water is supplied in small containers into which the birds cannot fall, should be provided for those more severely affected but still able to move about. For birds that are utterly prostrate or for those unable or not inclined to eat or drink, perfectly dry cages, well bedded with a supply of straw or dry grass, should be provided. All cages should have a certain protection from the rays of the midday sun, particularly those for prostrate birds.

Small cages for the care of the most severely affected birds may be placed to advantage on racks or tables raised about 4 feet from the ground. A single box cage of this type was used at the recovery pens at Klamath Falls. Birds kept in it could be given drinking water through a pipette or medicine dropper and otherwise readily attended to. A series of such " receiving wards ", each large enough to hold 15 or 20 birds without crowding, will permit attention in an orderly manner and lessen the danger that extremely weak birds may become buried under others floundering about.

The methods outlined are in the nature of ideals to be sought wherever possible, though under the pressure of strenuous field operations they may not always be feasible. Outbreaks of duck sickness come quickly and often disappear in the same manner. There is no way to foretell their extent or severity, and birds usually are salvaged as best they can be with the facilities at hand. Let

it not be forgotten, however, that a duck rescued is equivalent to a duck raised. Madsen (*45, p. 109*) has estimated that, under conditions prevailing at Great Salt Lake, ducks may be reclaimed at a cost of 5 to 10 cents apiece, which is certainly trivial compared with the cost of game-bird propagation. In former severe outbreaks it was estimated that, had facilities been suitable and funds ample, 25,000 to 50,000 birds could have been salvaged on the Bear River Marshes alone.

Since the desire to feed is the last of the impaired major impulses to be regained by birds recovering from duck sickness, the question of food does not enter into the care of sick birds until they have made substantial progress toward recovery. The period during which they need to be fed is not long—usually not more than 4 to 6 days and, in the case of individuals captured while recuperating, the period of detention need be only a day or two. Ordinarily nothing practical can be done in the feeding of the highly insectivorous shore birds, and for this reason they should be released as soon as they regain their feet.

At Klamath Falls rolled barley was a satisfactory and readily obtainable food for convalescing birds of most species, including such diverse forms as teals, coots, and Canada geese. The barley ration was supplemented, however, every few days with green feed in the form of water cress (*Sisymbrium*) or duck weed (*Lemna*). The latter, as collected, contained many snails and insects, thus furnishing animal food as well.

When the idea prevailed that duck sickness was caused by the toxicity of certain soluble salts in alkali, the handling of affected birds in the manner described was referred to as the "fresh-water" treatment. It was inferred that fresh water, or at least the absence of more alkaline water, had effected the cure. With botulism determined as the cause, however, it will be well to reappraise the significance and merits of such treatment. In the first place there are to be borne in mind the circumstances surrounding the capture and subsequent treatment of birds that have been rescued, and the part these play in the high percentage of recoveries generally noted.

Ordinarily when sick birds are being gathered, those utterly prostrate are passed by, as also are the dead bodies that litter the mud flats by the thousands. The birds collected are either (1) those that are in the earlier stages of the onset, (2) those in process of recovery, or (3) those that have ingested sublethal doses of toxin. All the birds in the last two groups, and part of those in the first, have excellent chances for recovery, and any conclusions drawn from results attained with those and those only will be biased accordingly. The material on which such deductions are based is in fact hand picked and in no way reflects the true reaction of the disease. Were all the dead and nearly dead found in the field included, the percentage of recovery would be materially reduced.

It is to be remembered also that when birds are subjected to fresh-water treatment they usually are favored by several other factors, which though of the utmost importance to their recovery, have no connection with fresh water. Birds placed in a dry pen, sheltered from the heat of midday and the cold of night, safe from the

attacks of predatory creatures, the dangers of feather soaking and even drowning, often the fate of sick birds under field conditions, have advantages of far greater importance than any that might be derived from the mere oral administration of fresh water. Although there is reason to believe that fresh water, forcibly and carefully given to helpless birds, will aid somewhat in the restoration of normal physiological processes, there is no evidence that it has any direct curative or combative value in cases of botulism.

If the fresh-water treatment should consist merely of giving the affected birds access to water, of which they are to avail themselves as best they can, the results will be fatal in a large proportion of the cases, owing to feather soaking, chilling, or drowning. If attention cannot be given individual birds and if those in varied stages of the disease cannot be properly segregated, a policy of no water or of water only in proper containers is preferable to an open supply into which the helpless birds may flounder.

## PREVENTION

### WATER HANDLING

From the very nature of duck sickness the most effective measures of relief are those of prevention rather than cure. The malady is definitely associated with areas of shallow water or mud flats. Whereas formerly these mud flats with their thin film of water or innumerable pools, evaporating sometimes to dryness, were looked upon as the source of the toxic salts considered to be the cause of the malady, they now become an important link in the chain of etiological factors that lead to the production of the toxin of botulism (p. 62), and its subsequent ingestion by birds. Any break in the sequence of these essential factors or events will effectively prevent or terminate an outbreak of duck sickness.

In South Africa, where lamsiekte (botulism of types C and D) is contracted by cattle that, by reason of a phosphate deficiency, possess a depraved appetite for bones, carrion, or other toxin-producing media, the situation is met by rectifying the phosphate deficiency in the diet or else by removing all carrion from pasture lands. When this is done lamsiekte is curbed, not through elimination of the organism, which may still be abundantly present, but by severing one link in the chain of events through which cattle obtain doses of toxin. Were it possible to eliminate, with equal thoroughness, all toxin-producing media from infected areas, duck sickness also could be effectively controlled. With a host of diverse media present, however, and likely to be ingested by waterfowl, shore birds, or other species, the possibility of accomplishing this through any labored process of detection and removal is wholly out of the question.

It is possible, however, to eliminate mud flats and shallow-water areas, either by flooding sufficiently to submerge them or by evaporation to the point of dryness. By the first of these processes high temperatures, favorable to toxin production, are reduced, and through dilution and water movement, any toxin that may have been formed is dispersed or attenuated to the point of harmlessness.

Furthermore, replacing mud flats with deep water often makes infected areas less attractive as loitering or feeding grounds for waterfowl and shore birds. Even more effective severance of the etiological chain may be accomplished by complete dessication of the infected areas. The simple expedient of cutting off the water supply and allowing the flats to dry was used in combating duck sickness in the marshes at the mouth of the Jordan River, Utah, as early as 1911.

With the establishment and subsequent development of the Bear River Migratory Bird Refuge, steps were taken to meet the ever-recurring menace of duck disease. Rapid and effective handling of water levels was impossible through drainage alone, owing to the great expanse and the level character of the delta on which the refuge rests. It was found necessary not only to raise a barrier against an influx of saline water from Great Salt Lake itself but to subdivide the inclosed area by means of other dikes in such manner as to permit either deep flooding with fresh water coming from Bear River or complete drying of the various units and smaller sections of the refuge.

On April 3, 1928, in the act establishing Bear River Migratory Bird Refuge, Congress authorized an appropriation of $350,000 to carry on such a program. Work was begun in 1929, and by July 1930 the dikes surrounding 3 of the 5 units comprising the refuge had been practically completed. The engineering work of the whole project was finished during the next year. This included a great outer dike approximately 20 miles long, which in seasons of plentiful water supply can impound about 25,000 acres of water. By means of gates and drainage spillways as many of the units may be flooded as the seasonal water supply permits.

At clubs or on private estates in infected areas where artificial ponds are formed by the diking and flooding of lands, precautions must be taken to avoid conditions conducive to toxin production. Water levels should be reasonably deep (1 or more feet near shore and greater in the center). Water temperatures should be kept below 80° to 90° F. during midday by circulation or change of the water or by increasing its depth. Shore lines should be kept well defined and clean. Feeding should be either on sand or gravel beaches prepared for the purpose or in troughs away from the water; promiscuous broadcasting of grain in shallow water or on mud flats should be avoided.

### FRIGHTENING MEASURES

The employment of frightening measures to drive waterfowl out of known infected areas has been resorted to with marked beneficial results on the Bear River flats. As early as 1921 officials of the game department of Utah adopted the practice of patrolling the flats, beginning early in August of each year (*45*). At the first signs of duck sickness, high-powered rifles were used to keep the flocks of healthy birds away from these areas. This was continued until fall rains, a rise in water level, or the lowered temperatures of October ended the possibility of an outbreak. The practice of rifle patrol, instituted and carried out by State officials from 1921 to 1928, was continued by Federal officials even after the establish-

ment of the Bear River Migratory Bird Refuge. In the short-lived but severe outbreak of August 1929 it was considered that gunfire, which drove flocks of healthy birds away from an infected area at the mouth of the Bear River, did much towards preventing an even greater epizootic.

### SANITATION

Disposal of the bodies of dead birds found in duck-sickness areas was one of the earliest of the measures used against the disease in Utah (p. 33). The procedure appeared to be logical and it probably did some good, even though the futility was soon impressed on the small crew of workers then participating in the work. Madsen's description (*45*) of these early operations is quoted on page 33.

The present study has definitely established the fact that the bodies of birds dying of duck sickness are excellent media for the production of toxin and may become the direct source of infection for other birds (p. 59). Sarcophagid larvae, which have developed in these bodies, also are sources of toxin and are likely to be picked up by shore birds as well as ducks. There is no question that the removal and proper disposal of dead bodies reduces in the aggregate the toxin available to birds, but evidence still is lacking as to the degree of improvement attained thereby. In view of the fact that a host of other toxin-producing media, including the remains of insects and various other invertebrates, as well as grain and decaying vegetation, may be contributing to the general infection, even energetic measures of body disposal may result in only a slight improvement. Until more is learned by field experimentation of the role of dead bodies in a duck-sickness outbreak, it would seem that efforts might better be spent in frightening healthy birds away from body-strewn areas, and in the rescue and subsequent cure of afflicted birds. The case is quite different from that of lamsiekte in South Africa, where the clean-up of carrion in infected pastures has brought beneficial results. There the sources of toxin are relatively few and discernible; in duck sickness, the toxin may come from a multitude of media, some of them quite obscure.

Treatment of infected areas with antiseptics or other substances, with the object of destroying the causative organism, preventing toxin production, or neutralizing toxin already formed, is a matter to which some consideration has been given though no field experimental work on it has been done. The immensity of the infected areas and the difficulty of reaching submerged spots of toxin, as well as the deleterious effect of powerful antiseptics on vegetation and possibly even on wild fowl, are obstacles that at this time make such treatment impracticable.

Whether a chemical treatment of infected areas so as to change them from a condition of alkalinity to one of neutrality or even acidity with respect to the hydrogen-ion concentration, would improve matters is yet to be determined. It is a fact that the range of duck sickness as it occurs in epizootic form coincides, to a marked degree, with that of the alkaline waters of this country. It is true also that the toxin of botulism is elaborated to a greater degree or in more potent form in alkaline media. The prospect of attacking the duck-sickness problem, however, through altering on an extensive

scale the hydrogen-ion concentration in waters frequented by the birds does not appear promising, though the procedure may be worth trial in localized spots of infection.

## SUMMARY

Earlier studies of disastrous outbreaks of what has been termed "western duck sickness", summarized in bulletins issued by the Department of Agriculture in 1915 and 1918 (*70*, *71*), pointed to the cause as "the toxic action of certain soluble salts found in alkali." Later evidence that this explanation was not adequate led the Bureau of Biological Survey to resume its studies in 1927, and by 1931 the results attained had removed the problem from the field of chemical toxicology to that of bacteriology. The malady is now recognized as a form of botulism, a disease caused by the toxin produced by a common saprophytic and anaerobic bacterium, *Clostridium botulinum*, type C.

This organism, thriving under conditions of decay, had previously been recognized as the cause of more or less localized outbreaks of limberneck among domestic poultry and forage poisoning in livestock. Its association with the extensive wild-fowl epizootics has not only altered earlier concepts of this ailment of wild birds, but it has changed, even more radically, the bacteriologist's idea of the prevalence, history, and importance of *Clostridium botulinum*, type C.

In distinction from many contagious bacterial diseases, outbreaks of botulism, which is simply a form of food poisoning, are not dependent on a weakened or predisposing condition of the victim. Factors controlling the prevalence of the disease are largely those that affect the welfare of the organism itself and the production of its toxin. Among these are the prevalence of dead organic matter, animal or vegetable; an alkaline environment, which plays an important part in the bacterial processes of toxin production; a condition of shallow water or stagnation, preventing toxin dilution or dispersal; and relatively high temperatures.

Diagnosis of botulism as the cause of duck sickness has been based in this study on (1) the similarity of the clinical picture of the disease in the field with that produced experimentally by the administration of the toxin of pure cultures of type C *botulinum;* (2) the frequent recovery of the causative organism from the tissues of affected birds in distinction from its absence from the tissues of healthy birds; (3) the demonstration in the field of the toxin of type C *botulinum* in foods and water commonly ingested by birds; and (4) on the fact that the incidence, course, and disappearance of duck sickness in the field conforms to the influence of environmental factors in a manner highly suggestive of botulism.

This study has shown that such bird-food items as sarcophagid-fly larvae and miscellaneous insect debris (acceptable to shore birds and ducks), submerged grain (eagerly sought by ducks), and the bodies of birds dying of the disease (a common food item of gulls) are some of the channels through which the poison may be taken. Toxin also has been demonstrated in the mud of infected areas rich in organic matter, and even the water of small pools may harbor the poison produced in nearby media.

The toll from the disease, though varying greatly from year to year, must be looked upon as the greatest drain upon western waterfowl due to any single natural agency. An estimated loss of a quarter of a million birds at the north end of Great Salt Lake in the summer and fall of 1932 points to the current importance of the malady as a destroyer of wild life. Not only ducks but a multitude of other birds succumb: at present the list of known victims comprises 69 species, in 21 families of wild birds. Although various vertebrates other than birds are susceptible to the toxin of type C *botulinum*, evidence points to the fact that human beings are relatively, if not absolutely, immune to oral doses.

The history of western duck sickness has been traced, with a fair degree of accuracy, back to the early nineties of the last century. The year 1910 marked the point when Nation-wide attention was first called to the malady as a result of the publicity given the disastrous outbreak in the marshes about Great Salt Lake in that year. Since that time the disease has occurred at an ever-increasing number of localities in the West, and today the distribution of the disease among North American wild fowl conforms in general to the region of alkaline waters and soils of the Western States and the southern Canadian Provinces. Although the causative organism was probably endemic in North America long before it was evidenced in outbreaks of duck sickness, it is apparent that conditions conducive to epizootics have been accentuated by man through his utilization of water supplies. This often has resulted in the creation, during periods of hot weather, of alkaline sinks and areas of shallow, stagnant water, mud flats, and their associated decaying organic matter, in which toxin may be produced.

Remedial measures may be in the form of direct treatment or prevention. Among the former are the rescue and subsequent care of afflicted birds. These will save many that would otherwise succumb to such attendant hazards as the heat of midday, attacks of predators, feather soaking and chilling at night, and even drowning. The use of antitoxins under field conditions is impractical. At points of local infection much sickness may be prevented by frightening the birds, through rifle fire, from dangerous ground.

More lasting and effective means of prevention, however, lie in modifying or eliminating conditions that favor the development of the organism and the evolvement of its toxin. By flooding mud flats and shallow, stagnant water areas with deep or flowing water, temperatures are reduced and, through a process of dilution, preformed toxin may be attenuated to the point of harmlessness. The expedient of temporarily cutting off all water from infected areas also has been used effectively where the ground may be completely desiccated and thus become unattractive to birds in midsummer.

An inadequate water supply and fluctuating water levels are the dominant environmental factors conducive to outbreaks of duck sickness. Often these are the direct result of man's increasing diversion of the supply from favorite wild-fowl areas, where formerly reasonable and more nearly constant water depths were maintained throughout periods of hot weather. Unless these conditions can be restored, duck sickness will continue to take, even increasingly, its annual devastating toll of western wild fowl.

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# EXPERIMENTS WITH FORAGE CROPS AT THE FORT HAYS BRANCH STATION, HAYS, KANS. 1913 TO 1928

By

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Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

# EXPERIMENTS WITH FORAGE CROPS AT THE FORT HAYS BRANCH STATION, HAYS KANS., 1913 TO 1928 [1]

By R. E. GETTY

Formerly *associate agronomist, Division of Forage Crops and Diseases, Bureau of Plant Industry*

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## INTRODUCTION

The Fort Hays Branch Station of the Kansas Agricultural Experiment Station [2] (fig. 1) is located about one half mile south of Hays, the county seat of Ellis County, Kans., in the center of the hard winter-wheat belt of west-central Kansas. It is about 100 miles west of the ninety-eighth meridian, which is ordinarily considered

[1] These experiments were conducted under a cooperative agreement between the Bureau of Plant Industry, U.S. Department of Agriculture, and the Kansas Agricultural Experiment Station.

[2] A brief historical sketch of the station and the section in which it is located appears in the following publication: SWANSON, A. F., CEREAL EXPERIMENTS AT THE FORT HAYS BRANCH STATION, HAYS, KANS., 1912 TO 1923. U.S. Dept. Agr. Tech. Bull. 14, 56 pp., illus. 1927.

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the eastern boundary of the Great Plains, and at an altitude of 2,000 feet.

The results of experiments conducted at this station in the production of cultivated forage crops for the period 1913–28 are reported in this bulletin.[3] Occasional reference is made to earlier unpublished results, especially with alfalfa, for the period 1902–12.

The experiments, except certain ones with alfalfa, were conducted on upland soil under dry-farming conditions representative of an extensive area in the central Great Plains. Sorghums have had the leading place in these experiments and the results are of most value to the northern part of the sorghum belt, namely, western Kansas and adjacent territory in eastern Colorado and southwestern Nebraska.

Sorghums are now the principal cultivated forage crops of this section. The increase in the acreage of sorghums was very rapid

FIGURE 1.—View on the Fort Hays Branch Station at Hays, Kans., in the heart of the Kansas wheat belt. Wheat farming requires expensive machinery which results in a large overhead and often makes it less profitable than a combination of forage crops and livestock.

from 1885 to 1912, and there has been some increase since that time, but with wide fluctuations. Increases in sorghum acreage usually follow periods of poor returns from wheat and corn, and decreases in sorghum are associated with cycles of unusual profits from either or both of the cereals named. Over 2,000,000 acres of sorghums have been grown annually in Kansas during the past 10 years. About one third of this acreage is planted to sorgos, almost wholly for forage purposes. The remainder consists mainly of kafir, milo, and feterita, in the order named. These are commonly known as grain sorghums, but kafir is grown usually for both forage and grain.

Sudan grass ranks next in importance. In the 20 years since it was first grown commercially in Kansas, its acreage has increased to

[3] The data contained in this bulletin have been given, in part, in previous publications, as follows: With reference to sorghums, U.S. Dept. Agr. Bulls. 383 and 1260; Sudan grass, U.S. Dept. Agr. Bull. 981; and for all work up to 1919, inclusive, in Kans. Agr. Expt. Sta. Bull. No. 225. Reference has been made to certain subjects in Farmers' Bulls. 793, 1126, and 1158 of the U.S. Department of Agriculture.

more than 100,000, about equally divided between the eastern and western halves of the State.

Millet was the leading cultivated hay crop of the early settlers, reaching its maximum of more than 500,000 acres in Kansas in 1885. With the introduction of improved sorghums and Sudan grass, millet has continuously declined in importance, and now totals less than 100,000 acres.

Alfalfa increased rapidly in acreage from 1890 to 1910 on the narrow strips of bottom land along small streams in western Kansas. It reached a peak of 283,574 acres in the western 46 counties in 1910 but has since decreased steadily to less than half this acreage. The decline is largely accounted for by the increasing difficulty in obtaining and maintaining stands of the crop.

Sweetclover and certain annual legumes have attracted some interest in recent years but are as yet relatively unimportant under dryland conditions. A few thousand acres of sweetclover are grown largely on low, sandy river-bottom land, as along the Arkansas River.

Prairie hay was an important source of feed with the early settlers. At the present time it is produced mainly on irregular and scattered areas in the draws where the soil moisture is increased by the run-off from surrounding areas, and the land is perhaps too rough to plow. Big and little bluestem are the most prominent grasses in such places.

The earliest cattlemen depended entirely on native pastures, of which buffalo grass and the grama grasses are the principal constituents. They suffered great losses, however, in severe winters when snow covered the ranges and when the water supplies in the creeks were frozen. As land came into cultivation, stockmen began raising supplementary feeds, thus avoiding many losses. Only in very recent years, however, has the reliance on native pastures alone disappeared, as disaster overtook one after another of the few old-time ranchers who refused to adapt themselves to modern methods.

On land that appeared adapted to the production of cultivated crops, large areas of the native grasses have been plowed under. The diversion of grazing lands to cultivated crops is greatest in periods of favorable rainfall and high prices. Some cultivated land usually reverts to grass in periods of depression or low rainfall, but the tendency has been to bring more and more of the level land into cultivation. In some localities it would seem that too large an acreage of grassland had been plowed up for wheat, but where farming is diversified it usually has been possible to devote a considerable acreage to wheat and yet grow enough forage crops to support an increased number of livestock. During the period of rising land values and tax rates when the decreased expense of producing wheat due to the introduction of new machines, such as the combine, and favorable prices made wheat production profitable some of the best farmers deemed it unwise to devote level land to pastures since it required 5 to 10 acres of grassland in addition to supplementary winter feeds to support one animal.

Now that the idea of cultivated forage crops for winter feeding has been generally accepted, the problem seems to be the choice of crops and varieties, their improvement, and the development of the most effective methods of culture and utilization.

Sorghums have best met the need for high-yielding forage crops that can be grown cheaply on any land suited to cultivation. By the use

of silos, it has been found possible to double the acre-feeding value of sorghums and hold feed in reserve for a period of years. This latter is of special importance, for, at best, the dry-land sections are subject to partial or complete crop failure in many seasons.

Sudan grass has helped to meet the need of a catch crop for hay production and of a grass that will provide abundant pasturage during the late summer when the native grasses are unproductive.

Sorghums, Sudan grass, and the millets (the forage crops best adapted to upland conditions) are all high in carbohydrates and relatively low in protein. There remains a need for legume crops that can be grown to supply this protein, and with the decline in alfalfa production in recent years the need has become greater. So far, it has appeared more practical for most stockmen to buy protein concentrates, such as cottonseed cake, rather than attempt to grow any of the legumes extensively under upland conditions.

## SOILS

The upland soil, or wheat land, on which nearly all of the experimental work was done, belongs to the black earth soil belt of the United States and is similar to the black earth of Russia, Rumania, Argentina, and Canada. The surface 8 to 18 inches is medium heavy, relatively dark, and very fertile. The subsoil is a heavier, more compact, and lighter-colored silty clay loam or clay of excellent moisture-holding capacity. The black earth soils occupy a belt extending north and south across Kansas, bounded on the east by a line running approximately through Smith Center, Osborne, Ellsworth, Lyons, Kingman, and Anthony and on the west by a line running approximately through Meade, Dighton, Hoxie, and Oberlin.

The black earth soils, comprising 55 percent of the total land area of the 46 counties of western Kansas, differ very little in texture and crop adaptation from the Colby silt loam adjoining them on the west and making up 35.8 percent of this area. The difference in these soils is mainly in productiveness due to the thickness of the dark surface layer, the percentage of nitrogen and humus, and the higher rainfall in the black earth belt. Both series come within the farmers' classification of hard land in contrast with the sandy land more commonly found adjacent to the Arkansas River and southward in Kansas.

The bottom lands on which some of the alfalfa experiments were located lie along Big Creek and are similar to soils of the Cass series, one of the important alluvial soils of the Great Plains. It is a dark, rich, alluvial soil with a water table at an average depth of 20 feet, to which the roots of successfully established alfalfa penetrate.

All of the soils in this section are subject in varying degrees to drifting from hard winds, usually in the late winter and early spring. This factor is sometimes serious at the Hays station when fields are left smooth and bare through the winter, as when row crops are removed or when fall-seeded wheat lacks moisture to grow and cover the ground. Soil drifting is controlled by roughly cultivating or listing the land at right angles to the prevailing winds.

## CLIMATIC CONDITIONS

### PRECIPITATION

The average annual precipitation at the Fort Hays station is 22.8 inches, as computed from a continuous 61-year record of the United States Weather Bureau from 1868 to 1928, inclusive. The highest annual rainfall was 35.4 inches in 1878 and the lowest 11.8 inches in 1894. Within the period of the forage-crop experiments at the Hays station, from 1913 to 1928, the average precipitation was 22.09 inches; the highest, 34.14 inches in 1915; the lowest, 14.51 inches in 1924. Comparison of the data for the 61-year period with those for the last 16 years at the Hays station and a study of long-time records at other dry-land points as well show the fallacy of the popular theory that rainfall follows the plow. Attempts have often been made to prove that wet and dry seasons prevail in approximately definite cycles, hoping from this study to be able to formulate a plan for reliable forecasts of rainfall conditions one or more years ahead.[4]

More than three fourths of the annual rainfall is received during the 6 months, April 1 to September 30, the season of most active crop growth. The exact distribution for any 1 year, however, is highly uncertain and has ranged from more than 10 inches in 1 month down to as little as 0.16 of an inch in 4 months. The heavier summer rains are often torrential, and much of such precipitation is lost from runoff; on the other hand, many showers in summer are so light that they scarcely penetrate the soil and evaporate so quickly that they seem to be of little, if any, benefit. Monthly and annual precipitation records at Hays, Kans., for 1913–28, inclusive, are given in table 1.

TABLE 1.—*Monthly and annual precipitation at the Fort Hays Branch Station, Hays, Kans., for the 16-year period 1913–28, compared with the averages for the Hays station and vicinity for the 61-year period, 1868–1928*

[Data in inches. T=trace. Adapted from published records of the U.S. Weather Bureau]

| Year | Jan. | Feb. | Mar. | Apr. | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1913 | 0.36 | 0.68 | 0.41 | 2.78 | 5.72 | 3.53 | 0.63 | 0.11 | 4.80 | 0.25 | 0.72 | 3.11 | 23.10 |
| 1914 | .04 | .42 | .15 | 2.31 | 2.36 | 3.39 | 2.77 | 2.63 | .60 | 1.33 | T | .63 | 16.63 |
| 1915 | .68 | 1.80 | 1.74 | 3.13 | 6.82 | 3.97 | 8.18 | 4.11 | 2.44 | .93 | .30 | .04 | 34.14 |
| 1916 | .53 | .15 | .31 | 2.21 | 1.63 | 5.88 | .30 | 1.97 | 1.26 | 1.14 | .02 | .61 | 16.01 |
| 1917 | .11 | T | .07 | 1.96 | 1.72 | 2.15 | 1.46 | 5.73 | 1.84 | .09 | 1.64 | .15 | 16.92 |
| 1918 | .80 | 1.15 | 1.71 | 2.49 | 4.79 | .53 | 3.04 | 1.76 | 1.42 | 2.41 | 1.10 | 2.38 | 23.58 |
| 1919 | T | 2.18 | .33 | 4.51 | 6.85 | 3.51 | 1.16 | .77 | 3.32 | 1.81 | 1.54 | .15 | 26.13 |
| 1920 | .05 | .37 | .30 | 2.04 | 3.32 | 1.87 | 1.89 | 5.11 | 1.56 | 3.58 | .73 | .46 | 21.28 |
| 1921 | .40 | .10 | .49 | 3.58 | 2.59 | 3.67 | 3.36 | 3.04 | .68 | .05 | 0 | .50 | 18.46 |
| 1922 | T | .93 | 1.71 | 4.51 | 2.61 | 2.18 | 4.20 | .81 | .43 | .32 | 1.28 | T | 18.98 |
| 1923 | T | .10 | 1.04 | 1.63 | 3.97 | 5.96 | .70 | 4.15 | 4.52 | 4.37 | .29 | .37 | 27.10 |
| 1924 | .31 | .26 | 1.81 | 1.05 | 3.19 | .77 | 2.32 | 1.95 | 1.03 | .46 | .25 | 1.11 | 14.51 |
| 1925 | .05 | .24 | .38 | 4.27 | 1.01 | 4.13 | 6.73 | 3.33 | .99 | .75 | 1.12 | .02 | 23.02 |
| 1926 | .36 | 1.13 | 1.75 | .81 | 2.16 | 2.55 | 1.94 | .83 | 2.83 | .60 | 1.12 | .37 | 16.45 |
| 1927 | .04 | .98 | 1.85 | 3.09 | 1.84 | 8.03 | 1.82 | 6.63 | 2.80 | T | .03 | .10 | 27.21 |
| 1928 | .03 | 1.57 | 1.42 | 1.27 | 3.13 | 9.13 | 6.86 | 1.78 | .84 | 2.01 | 1.88 | .02 | 29.94 |
| Average, 1913–28 | .23 | .75 | .97 | 2.60 | 3.36 | 3.83 | 2.96 | 2.79 | 1.96 | 1.26 | .75 | .63 | 22.09 |
| Average, 1868–1928 | .49 | .85 | 1.01 | 2.32 | 3.27 | 3.37 | 3.29 | 2.99 | 2.26 | 1.42 | .76 | .77 | 22.80 |

[4] An interesting attempt of this kind was the following publication: EMMONS, C. H., THE EMMONS RAIN CHART AND CROP GUIDE. 32 p. Hill City, Kans. [c1927]. Mr. Emmons, then living at Hill City, Kans., classified the precipitation in 6-year cycles, 3 dry and then 3 wet years. He based this on a study of the average rainfall from 1881 to 1928 in North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Texas, Minnesota, Iowa, Missouri, and Arkansas. He also studied the long-time records at 10 selected stations in the western third of Kansas, and later included all records for the 145 stations in that part of the State. One of these alleged cycles has recently been completed (1923–26). The reader may judge from the table of precipitation data presented for the Hays station with what reliability, if any, the cycle theory can be applied to the rainfall at this station during the period 1913–28.

A very important factor in crop production is the reserve of available moisture in the subsoil. When rainfall is plentiful in the late summer or fall of one year, some very good crops are often produced the following season with relatively light precipitation during the growing period. Likewise, if the season begins with very little reserve moisture in the subsoil, crops are likely to suffer considerably at any time that the current rainfall is deficient, even for a short period. To judge the moisture available for crop production in any year at Hays, consideration should be given to the preceding year's record, as to what conditions prevailed after the preceding crop ceased to use moisture. The years 1914 and 1924 furnished notable examples of good crops produced with a light seasonal rainfall, but following a wet fall.

Some calendar years with approximately normal rainfall, or more, have been poor for crop production because of the unequal distribution of the rains. In 1913 the annual rainfall was about normal, yet one of the worst crop failures on record occurred because of poor distribution.

Hail cut crops to the ground on June 29, 1923, but sorghums, Sudan grass, and millets recovered fairly well. Lighter hail has occurred at other times in May, June, and July, but it has not been a factor of much importance in the results with forage crops. A very destructive hailstorm occurred on June 13, 1909. Forage crops usually recover from hail damage much better than the cereals, and, if necessary, early varieties can be reseeded up to July 1 with the prospect of a fair crop.

### EVAPORATION

The amount of water evaporated daily from a tank at ground level has been recorded from April 1 to September 30 throughout the years 1907–28. Monthly and annual totals are presented in table 2. Evaporation records are of particular value as an index to the combined effects of precipitation, temperatures, and wind. The data here presented afford in condensed form excellent comparisons of the crop-producing possibilities of different seasons. High evaporation indicates hot, dry, or windy weather, usually droughty. Low evaporation indicates cold, wet, or quiet conditions, usually a favorable condition when less than 10 percent below normal, but injurious to the germination, early growth, and maturity of sorghums when much below normal over a protracted period. Monthly totals exceeding 10 inches indicate drought, increasing in severity as the total evaporation rises. Where the 6-months total evaporation exceeds 50 inches it has been associated with ruinous drought extending over a considerable period.

TABLE 2.—*Monthly and seasonal evaporation from a free-water surface at the Fort Hays Branch Station, Hays, Kans., from April to September of each year, 1913–28*

[Data from the Division of Dry Land Agriculture]

| Year | Evaporation (inches) | | | | | | |
|---|---|---|---|---|---|---|---|
| | April | May | June | July | August | September | Seasonal, Apr. 1 to Sept. 30 |
| 1913 | 6.606 | 7.640 | 8.521 | 13.815 | 14.451 | 7.250 | 58.283 |
| 1914 | 5.758 | 5.094 | 9.282 | 9.256 | 9.817 | 7.889 | 47.096 |
| 1915 | 4.486 | 5.529 | 5.328 | 7.059 | 5.381 | 5.494 | 33.277 |
| 1916 | 4.228 | 7.037 | 7.731 | 12.201 | 11.125 | 7.909 | 50.231 |
| 1917 | 6.354 | 6.527 | 11.089 | 11.871 | 8.140 | 6.488 | 50.469 |
| 1918 | 4.325 | 7.491 | 8.936 | 9.062 | 11.244 | 6.511 | 47.569 |
| 1919 | 4.065 | 4.528 | 5.405 | 10.272 | 9.344 | 7.382 | 40.996 |
| 1920 | 4.783 | 4.682 | 8.117 | 9.646 | 6.291 | 6.257 | 39.776 |
| 1921 | 6.174 | 7.252 | 6.043 | 8.671 | 8.188 | 8.229 | 44.557 |
| 1922 | 4.388 | 5.912 | 7.931 | 8.258 | 10.531 | 10.300 | 47.320 |
| 1923 | 5.997 | 5.578 | 6.583 | 9.823 | 8.584 | 6.238 | 42.803 |
| 1924 | 5.483 | 6.782 | 7.738 | 10.835 | 10.325 | 7.459 | 48.622 |
| 1925 | 6.002 | 6.784 | 11.633 | 9.487 | 7.925 | 6.978 | 48.809 |
| 1926 | 5.501 | 7.357 | 9.382 | 11.408 | 11.159 | 7.227 | 52.034 |
| 1927 | 4.559 | 7.809 | 7.660 | 9.261 | 6.270 | 6.963 | 42.522 |
| 1928 | 6.407 | 6.454 | 4.965 | 8.002 | 8.159 | 8.321 | 42.308 |
| Average | 5.320 | 6.404 | 7.896 | 9.933 | 9.183 | 7.306 | 46.042 |

## FROST DATA

The dates of the last killing frost in the spring and the first one in the fall have been recorded by the United States Weather Bureau at Hays from 1892 to the present time. These dates are of particular importance for the fall season in this northern section of the sorghum territory, where midseason to late varieties may be killed prematurely in a season like 1918, for example, when frost came on September 20. The average date of the last frost in spring is April 30 and the first in the fall is October 12, giving an average frost-free period of 166 days.

Large departures from normal in about one fourth of the seasons add a marked element of risk, especially to sorghum production. The latest killing frost in the spring recorded at Hays occurred on May 27, 1907. It ruined the first crop of alfalfa, and corn had to be replanted. Other extremes of late frost were recorded on May 19, 1894; May 26, 1901; and from May 12 to 16 in 1895, 1904, 1914, 1923, and 1924. Frost was reported in September eight times in 37 years, the earliest being on September 17 in 1901 and 1903; others on September 20, 1918; September 26, 1912; and on September 29 in 1895, 1916, 1920, and 1924. Usually frosts as late as the last week of September only slightly affect results with sorghums, for the weather is ordinarily so cold from this time on as to permit but little development. Frost delayed 10 days or more beyond normal is rarely preceded as in 1927 and 1928 by sufficiently warm October weather to let sorghums ripen to any extent during that month.

### MAXIMUM AND MINIMUM TEMPERATURES

Temperatures throughout the season are of much interest in interpreting the results with warm-weather crops such as sorghums, Sudan grass, and millets; also in comparing sorghums with corn. The chief interest in the data recorded at the Hays station from April 1 to September 30 by the Division of Dry Land Agriculture centers around the maximum and the mean temperatures within the frost-free period. Often a warm period around the second to the last week in May, suitable for seeding sorghum, is followed by from 1 to 3 weeks of cold wet weather. This happened in 1915, 1916, 1917, 1919, 1923, 1924, 1926, 1927, and 1928, or in 9 of the 16 seasons, during the forage-crop experiments. While the latter part of May is the normal planting season for sorghums in this locality, the danger of sufficiently cold wet weather to interfere with their stands and early growth exists until after June 15.

The maximum temperature on record at Hays was 114° F. on June 25, 1911, and the next highest was 111° on July 14, 1913. By

FIGURE 2.—The disastrous effect of wind erosion on soils left unprotected is illustrated by the condition of this field near Hill City, Kans.

contrast, the maximum temperature for June was only 87° in 1915 and 1928. The relative severity of high temperatures for the different seasons is effectively indicated by the number of days registering 100° or above during July and August. During the hottest season, 1913, there were 36 such days, 13 of which occurred in one consecutive 14-day period, from August 3 to 16. During 1915 there were none, in 1927 only one, and in 1928 only three; in neither of the latter seasons was 100° recorded later than July 10. The year 1913 was one of severe drought while the last three named (1915, 1927, and 1928) were exceptionally favorable seasons. Corn thrived greatly in these cool wet seasons, but it suffered in other seasons approximately in proportion to the number of days registering 100° or more in July and August.

### WIND VELOCITY

Data on wind velocity at the Hays station have been recorded by the Division of Dry Land Agriculture in terms of average miles per hour for each 24-hour period from April 1 to September 30 for 1908

to 1928, inclusive. The measurements are taken 3 feet above the ground, in order to be near the average level of growing crops. The highest daily record was 27.2 miles on April 14, 1912, and the next highest was 27.1 on May 8, 1927. The latter date was notable for the great damage done in northwestern Kansas from soil drifting (fig. 2) and for injury to all growing crops, especially winter wheat (fig. 3), through so-called "electric winds." While the highest winds of the growing season are usually recorded in April and May, they are much less important to the growing of forage crops than the extremes occurring after July 1.

High winds in July and August, associated as they usually are with hot dry weather, may cause partial or total ruin to a corn crop in a

FIGURE 3.—Alfalfa in rows covered by soil blown from an adjoining wheat field.

day or two at the pollinating stage. Sorghums are noted for enduring such conditions much better, and if injured they usually make more or less recovery as soon as the drought is relieved. High winds in September may cause the sorghums to lodge and may also dry and blow off the lower leaves prior to the ripening of the grain. These latter conditions have prevailed in seasons like 1925, 1927, and 1928, when an extra-tall, succulent growth of sorghums was suddenly checked by the near exhaustion of its supply of soil moisture. High winds often cure and destroy within a few days the foliage of sorghums previously killed by frost, and they may also cause the stalks to lodge more readily than before frost. Winds may merely break the heads over and cause a great loss of grain. This situation proves a serious limitation to the practice of letting sorghums stand for harvesting with a combine.

Days with average wind velocities of 20 miles or more per hour are considered very severe for growing crops, both as to mechanical injury

and the transpiration of moisture. Days having 15 miles or greater average velocity are considered severe, but not necessarily ruinous. Months with an average of 10 percent or more above normal are usually associated with other droughty factors noticeably injurious. Normal wind velocities for April to September, respectively, are 10.3, 8.8, 7.6, 6.7, 6.5, and 7.6 miles per hour.

A summary of the most important of the climatic data discussed is given in table 3.

TABLE 3.—*Summary of various climatic records for the Fort Hays Branch Station, Hays, Kans., 1913–28*

[Data for precipitation and frost dates adapted from reports of the U.S. Weather Bureau; other factors adapted from records of the Division of Dry Land Agriculture]

| Year | Precipitation for the 6 months ending— | | Evaporation | | Dates of killing frost | | Days with maximum temperature of 100° F. or above in July and August | Days in which the wind velocity averaged 10 miles or more per hour from— | |
|---|---|---|---|---|---|---|---|---|---|
| | Mar. 31 | Sept. 30 | Total, Apr. 1 to Sept. 30 | Number of days with ½ inch or more during July and August | Last in spring | First in fall | | Apr. 1 to June 30 | July 1 to Sept. 30 |
| | *Inches* | *Inches* | *Inches* | | | | *Number* | *Number* | *Number* |
| 1913 | 3.12 | 17.57 | 58.28 | 22 | Apr. 12 | Oct. 17 | 36 | 43 | 30 |
| 1914 | 4.69 | 14.06 | 47.10 | 4 | May 13 | Oct. 25 | 18 | 31 | 13 |
| 1915 | 6.18 | 28.65 | 33.28 | 0 | Apr. 3 | Oct. 5 | 0 | 22 | 8 |
| 1916 | 2.26 | 13.25 | 50.23 | 10 | May 3 | Sept. 29 | 22 | 23 | 26 |
| 1917 | 1.95 | 14.86 | 50.47 | 9 | May 8 | Oct. 8 | 15 | 43 | 13 |
| 1918 | 5.54 | 14.03 | 47.57 | 7 | May 1 | Sept. 20 | 21 | 31 | 11 |
| 1919 | 8.40 | 20.12 | 41.00 | 3 | Apr. 17 | Oct. 10 | 14 | 19 | 13 |
| 1920 | 4.22 | 15.79 | 39.78 | 0 | Apr. 27 | Sept. 29 | 7 | 25 | 9 |
| 1921 | 5.76 | 16.92 | 44.56 | 0 | May 3 | Oct. 8 | 6 | 25 | 12 |
| 1922 | 3.19 | 14.74 | 47.32 | 3 | Apr. 18 | Oct. 9 | 11 | 21 | 24 |
| 1923 | 2.74 | 20.93 | 42.80 | 2 | May 16 | Oct. 21 | 6 | 30 | 15 |
| 1924 | 7.41 | 10.31 | 48.62 | 7 | May 15 | Sept. 29 | 10 | 24 | 20 |
| 1925 | 2.49 | 20.46 | 48.81 | 2 | May 1 | Oct. 9 | 11 | 28 | 10 |
| 1926 | 5.13 | 11.12 | 52.03 | 9 | Apr. 28 | Oct. 24 | 17 | 26 | 30 |
| 1927 | 4.96 | 24.21 | 42.52 | 2 | Apr. 22 | Nov. 2 | 1 | 28 | 9 |
| 1928 | 3.15 | 23.01 | 42.31 | 2 | Apr. 16 | Oct. 22 | 3 | 24 | 18 |
| Average | 4.45 | 17.50 | 46.04 | 5 | Apr. 28 | Oct. 11 | 12 | 28 | 16 |

In table 3 the precipitation data are arranged to show: (1) The quantity received during 6 months previous to the growing season, which gives a fair basis for comparing different seasons as to relative amounts of available soil moisture; (2) the amounts for the 6 growing-season months. Where the October-to-March precipitation was well below normal, as for 1913, 1916, 1917, 1922, 1923, 1925, and 1928, crops depended almost entirely on rain received while growing. In the first 3 years named this was inadequate; in the latter 3 it was abundant for good crops. This indicates about a 50 percent prospect of good forage-crop yields if the growing season opens without a reserve of moisture. Where precipitation shown in the first column is about normal, as in 1914, 1920, 1926, and 1927, wide variations occurred in the succeeding crops, yields being generally in proportion to rainfall received while growing. Results also varied for the seasons that opened with the greatest reserves of moisture, but it is noteworthy that in one of these seasons (1924) it was possible to produce fairly good crops of nearly all kinds with only 10.31 inches of rainfall during the growing period.

The data for evaporation, maximum temperatures, and wind velocity indicate clearly the relative merits of the seasons; the lower the figures shown, the better the crop returns.

### INSECT PESTS

The leading insect pests affecting the experimental work with forage crops have been grasshoppers and chinch bugs.

Widespread outbreaks of grasshoppers have occurred throughout this section at varying intervals ever since its earliest agricultural history. The most severe in recent years was that of 1913 when from late June to early September they did much damage to Sudan grass, alfalfa, annual legumes, and corn; medium injury to sweetclover, millet, and milo; but relatively little to the other sorghums. They have since appeared every summer in varying numbers, often sufficient to do considerable damage. However, since 1913 they have been checked through the spreading of poisoned bran mash, so that they have not greatly damaged the forage-crop experimental work at the Hays station.

Chinch bugs do considerable damage in the eastern two thirds of Kansas, but are of little, if any, importance farther west. At the Hays station they do some damage to milo, Sudan grass, corn, barley, and millet, and occasionally to sorghums other than milo, particularly feterita. Legumes are not affected, and juicy-stalked sorghums of the sorgo and kafir types, while often thickly infested, show comparatively little injury. Lodging of tall sorgos is, however, sometimes increased by the bugs. Chinch bugs are ruinous to milo, and in 1910, 1911, and 1913 they were injurious to several other crops at the station; they were definitely injurious to milo and feterita experiments in 1917, 1926, and 1927. In most other years they have been present in limited numbers.

### RODENTS AND BIRDS

Rabbits are always sufficiently numerous in western Kansas to cause some damage. At the Hays station they have usually destroyed any soybeans not fenced, and in 1924 they destroyed some tepary beans. Rabbits rarely attack tepary beans, however, and have let cowpeas alone. They eat almost any small isolated plot of tender vegetation, especially during the winter, including wheat, alfalfa, sweetclover, and perennial grasses.

Pocket gophers are a common pest in the alfalfa fields. Ground squirrels often steal newly planted corn and sorghum, especially when the field adjoins prairie land. Neither of these animals has, however, seriously affected the experimental work here reported.

Sparrows and blackbirds have usually attacked the heads of a few of the earliest maturing grain sorghums, such as Freed and Early White milo. The sparrows persist, irrespective of means used to scare them, but blackbirds have been readily discouraged by shooting among them on several consecutive days. Bird injury has been negligible after the majority of sorghums headed.

### DISEASES

Head smut of sorghums (*Sorosporium reilianum* (Kühn) McAlp.) was a factor of importance in the experiments with Red Amber sorgo in 1924 and has affected it to some extent in several other

seasons since 1919. Leoti Red sorgo also suffered from this to a lesser but conspicuous extent in 1924, and showed a few heads of this smut in other seasons. This disease lives over in the soil and does not yield to seed treatment, but it has been almost eradicated by the use of hand-selected seed and by seeding the sorghums on wheat-stubble land each year. Other sorgos and kafirs are also subject to this smut, but in so minor a degree that its control presents no problem.

Covered kernel smut (*Sphacelotheca sorghi* (Link) Clint.), very commonly infecting up to 50 percent of the heads of sorgos and kafirs in farmers' fields of the section, has not been a factor in the sorghum experiments at the Hays station. It scarcely ever occurs when clean hand-selected seed is used from year to year, as in this work, but, if

FIGURE 4.—Double disking wheat stubble in the fall in preparation for seeding sorghums the following spring. Early preparation of the soil greatly improves the chances for a good sorghum crop.

present, it can be easily controlled by copper carbonate and other seed treatments.

Two leaf diseases of sorghum and Sudan grass are usually present; namely, bacterial stripe, caused by *Bacterium andropogoni* E. F. Smith, commonly known as red spot, and the bacterial streak disease, caused by *B. holcicola* Elliott. Neither of these diseases has interfered seriously with the results.

The older alfalfa stands have shown in recent years such a rapidly increasing amount of disease of the crowns and roots that the acreage is being steadily reduced.

Mammoth Russian sunflowers, planted in 7 years of the experiments, died regularly at or before the beginning of bloom. A leaf rust was conspicuous on these plants.

Leaves of all the cowpeas seeded in a variety test May 29, 1928, rusted and dropped off, and the plants died during the exceptionally wet cold weather that lasted through June.

### EXPERIMENTAL METHODS

Most of the experiments were conducted on $\frac{1}{10}$-acre plots or on duplicated or triplicated $\frac{1}{20}$-acre plots. The $\frac{1}{10}$-acre plots were used mainly for alfalfa and were usually duplicated; in one experiment on width of rows there were four replications. Sorghums, Sudan grass, millets, and sweetclover were commonly grown on $\frac{1}{20}$-acre plots. With crops of minor importance grown primarily for observation and not for yields, smaller areas were often used, generally $\frac{1}{100}$- or $\frac{1}{50}$-acre plots for sorghums and annual legumes. Numerous nursery trials of grasses, sweetclover, and alfalfa were made in rows either 1 or 2 rods long and usually 36 to 42 inches apart.

It has been a regular practice to seed the sorghum, Sudan grass, and millet experiments on some uniform upland field that grew small grain, usually winter wheat, the preceding year (fig. 4). Rotation of the land has been irregular as to the legumes.

Forage yields are reported for the total crop on an air-dry basis, including the seed crop, if any. All sorghum grain yields are on a basis of 56 pounds per bushel. Acre yields for each year of the experiment are usually shown throughout this publication; these yields are the averages for all replications.

## SORGHUMS

### VARIETY TESTS

The comparisons of sorghum varieties were conducted in two general classes of experiments: Tests of the more important varieties in plots of sufficient size to afford reliable yield data; tests of selections, introductions, and other minor varieties in single rows, primarily for observation and further selection.

The varieties for these tests were obtained from local sources, from State experiment stations in the Great Plains area, and from the United States Department of Agriculture. The list varied considerably from year to year as new varieties were constantly obtained, and some of the older ones were discontinued as being unworthy of further attention. Changes of the serial number identifying a variety were sometimes made as improved selections became available. Since Hays is in the northern part of the sorghum belt, most attention was given to early and midseason varieties. Both forage and grain-producing types were included, but without attempting to include all of the grain sorghums. Through an informal agreement with the Division of Cereal Crops and Diseases, the sorghum varietal tests were conducted cooperatively with that unit in 1919 and in the period 1924–28.

The sorghum variety tests were begun on a small scale in 1913, but due to extreme drought and to insect attacks they were almost a failure. The project was more fully organized in 1914 and was conducted on duplicate $\frac{1}{20}$-acre plots for 1914–23. Both plots were usually seeded at the same date, but in 1915 and 1921, 2 weeks or more elapsed between the first and second replications. This latter method lessened the risks in obtaining a stand and also permitted each variety to show more fully its reactions to the season. In 1924 the experiments were placed definitely on a plan of three replications, seeded, respectively, about May 15, June 1, and June 15. This plan was continued in succeeding years.

The sorghums were seeded regularly in 40-inch rows, usually 6 rows 110 feet long to each plot, only the inner 4 rows being used in determining yields. Tillage methods (fig. 5) calculated to permit maximum yields were followed uniformly within any 1 year's tests, but varied from year to year. Usually the varieties were seeded with a 2-row planter in shallow listed furrows. In a few seasons the crop was surface planted, with or without the use of disk-furrow openers. Satisfactory stands were the rule, due to extreme care in tillage practices (fig. 6) and to the use of hand-selected seed (fig. 7). Varieties brought in from outside sources ordinarily consisted of bulk seed and were generally at a marked disadvantage the first year. Kernel smut was rarely, if ever, noted in plots seeded with home-grown hand-selected seed, but often developed in varieties grown from untreated bulk seed not produced on the station. In the later years

FIGURE 5.—Sorgo fodder in shock in late autumn, with a part of the field blank-listed in preparation for the succeeding crop and to prevent soil blowing.

of the tests all varieties were treated uniformly with copper carbonate to insure freedom from kernel smut.

Head smut first appeared on the general farm of the station in 1919 in a large field of Red Amber sorgo. This smut was occasionally noted in the experimental projects in succeeding years, mainly in 1924, when there was enough to warrant noting the percentage. In 1924 the average percentage of head smut to total heads was highest in Red Amber, S.P.I.[5] 17548, with 19.9 percent; second highest in Leoti Red, F.C. 6610, with 12.6 percent; and third in Colman, F.C. 9134, with 6.3 percent. Other varieties with 0.6 percent or more were as follows: Early Sumac, F.C. 6611, 1.8 percent; Freed, F.C. 9033, 1.4 percent; Western Orange, F.C. 9073, 1.2 percent; Schrock, F.C. 1481, 1 percent; Black Amber, F.C. 7038, 0.8 percent; Sumac, F.C. 9130,

[5] C.I. indicates accession number of the Division of Cereal Crops and Diseases; F.C., of the Division of Forage Crops and Diseases; S.P.I., of the Division of Seed and Plant Introduction. In July 1926 the last named became F.P.I., indicating of the Division of Foreign Plant Introduction.

0.6 percent. Other sorgos and kafirs ranged from none up to 0.3 percent; but it was entirely absent in the milos and feteritas. With the discontinuance of Red Amber as a general field crop on the station about 1925, head smut again became rare and was rogued from the plots without being recorded.

Other plant diseases and insect problems were of relatively minor importance in these experiments. After 1913 grasshoppers, though present, were readily controlled. Chinch bugs damaged milo seriously and feterita to a lesser extent in 1917. In other years they were often present, but did not do appreciable damage. In the last years of the tests, subnormal milo plants were sometimes noted, and the question arose whether this was due to some disease or to chinch-bug injury.

FIGURE 6.—Snow retained in the lister furrows. This is one of the advantages derived from fall preparation of the seed bed.

The long duration of the sorghum varietal experiments permitted a study of these crops under a wide range of climatic conditions. The first 6 years, 1913–18, were relatively adverse and the last 10 years, 1919–28, rather favorable except in 1926. In the very severe drought of 1913, the highest forage yield was from Red Amber, 1.04 tons per acre. Certain other varieties yielded as follows: Western Orange, 0.84 ton; Black Amber, 0.61 ton; Sumac, 0.51 ton; Dwarf Yellow milo was a complete failure. The only grain yield from this group was from Black Amber, 3.2 bushels per acre.

The next most severe droughts occurred in 1916 and 1926. A very severe midsummer drought in 1917 ended in early August in time to permit good forage growth of those varieties having time to mature. A less severe drought through the latter part of the 1918 season cut the crop short and hastened maturity. The earliest killing frost of the 16 years occurred that year on September 20. The seasons of 1914, 1919, 1921, 1922, and 1924 were more nearly normal, the sorghums usually starting out favorably, but suffering to some degree from limited moisture toward the close of the season. In 1923 a

severe hailstorm on June 29 cut all plants to the ground (fig. 8). The hail left irregular stands, but was offset considerably by a wet fall and a late killing frost. There were 5 wet years—1915, when excessive moisture prevented seeding until several weeks after the normal date,

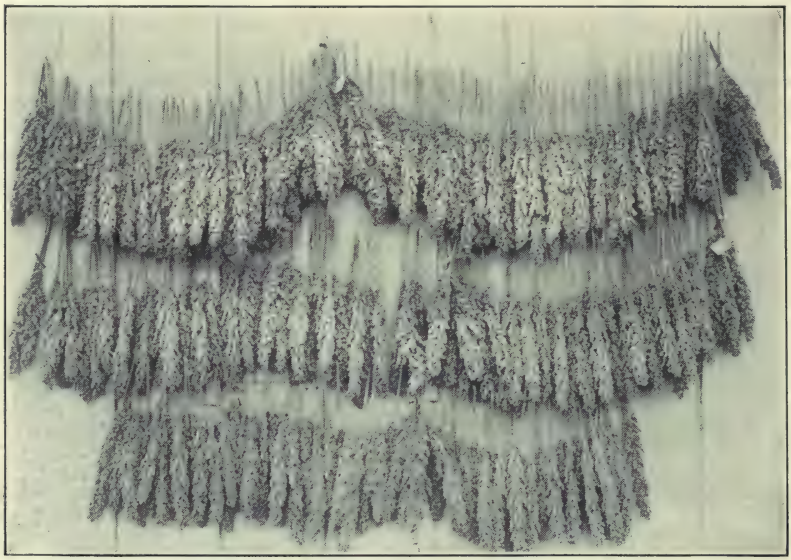

FIGURE 7.—Selected seed heads of sorghum hung up to cure. Handling the seed in this way improves the germination and does much to insure good stands.

FIGURE 8.—Hail damage to sorghum (left) and to corn (right), June 29, 1923. The sorghum recovered with only a slight loss of stand.

and a killing frost occurred while many varieties were still immature; 1920, the best season up to that time; 1925, when after a very wet summer a severe drought and high winds occurred in September, causing much lodging of the rank growth; and 1927 and 1928, the outstandingly favorable seasons of the entire period.

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TABLE 4.—*Average row space per plant and stalk, average height, and annual and average forage yields of sorghum varieties and 1 variety of corn (included for comparison), 1914–28*

[Yields of each variety compared with those of a composite check derived from the average yields of 10 varieties for the same years in which the variety was grown]

| Variety | Average row space | | Average height | Forage yields (air-dry) per acre | | | | | | | | | | | | | | | Average of— | | Relative yields [1] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plant | Stalk | | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Variety | Check | |
| | *Inches* | *Inches* | *Inches* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Percent* |
| Sumac | 6.9 | 4.4 | 70 | 3.31 | 5.43 | ..... | ..... | 3.01 | 5.09 | 7.03 | 3.93 | 3.23 | 3.04 | 3.14 | 4.86 | 1.28 | 6.23 | 5.68 | 4.25 | 3.27 | 130 |
| Kansas Orange | 7.3 | 4.6 | 78 | 3.83 | 4.97 | 2.94 | 3.86 | 2.61 | 2.57 | 7.30 | 3.86 | 2.85 | 3.44 | 3.18 | 4.60 | 1.56 | 6.12 | 5.63 | 3.95 | 3.09 | 128 |
| Colman | 6.1 | 4.2 | 75 | ..... | 5.60 | 2.45 | 2.93 | 3.27 | ..... | 6.69 | 3.32 | 2.84 | 3.41 | 2.61 | ..... | ..... | ..... | ..... | 3.68 | 2.97 | 124 |
| Atlas | 9.5 | 5.2 | 77 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.75 | 4.66 | 1.60 | 6.02 | 5.09 | 4.22 | 3.41 | 124 |
| Sourless | 7.4 | 4.6 | 77 | ..... | ..... | ..... | ..... | ..... | 3.20 | 7.22 | 3.58 | 2.90 | 3.08 | 3.06 | 5.10 | 1.50 | 5.85 | 5.23 | 4.07 | 3.31 | 123 |
| Straightneck | 7.4 | 4.7 | 84 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.40 | 3.30 | 4.68 | 1.29 | 5.60 | 5.34 | 3.94 | 3.27 | 121 |
| African "millet" | 8.4 | 4.9 | 68 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3.27 | 2.37 | 3.32 | 3.51 | 4.84 | 1.44 | 5.94 | 5.09 | 3.72 | 3.18 | 117 |
| Dakota Amber×sumac | 7.6 | 4.5 | 73 | ..... | ..... | ..... | ..... | ..... | ..... | 6.45 | 3.38 | 3.41 | 2.63 | 3.03 | 4.48 | 1.52 | 5.13 | 5.15 | 3.91 | 3.39 | 115 |
| Early Sumac | 6.7 | 4.3 | 64 | ..... | ..... | 3.13 | 3.14 | 2.43 | 3.40 | 5.56 | 3.57 | 2.68 | 2.78 | 2.79 | 4.19 | 1.38 | 4.82 | 4.69 | 3.43 | 3.01 | 114 |
| Red Amber | 6.6 | 3.9 | 77 | 2.93 | 5.72 | 2.52 | 2.94 | 3.13 | 3.45 | 5.07 | 3.11 | 2.74 | 3.41 | 2.88 | 3.71 | 1.56 | 4.47 | 4.42 | 3.47 | 3.09 | 112 |
| Leoti Red | 10.0 | 6.4 | 75 | ..... | ..... | ..... | ..... | ..... | ..... | 4.92 | 3.57 | 2.82 | 2.55 | 3.10 | 4.76 | 1.49 | 5.22 | 5.16 | 3.73 | 3.39 | 110 |
| Western Orange | 7.9 | 5.2 | 70 | 2.90 | 5.30 | 1.61 | 2.34 | 2.46 | 3.04 | 5.61 | 3.49 | 2.60 | 3.43 | 2.98 | 4.48 | 1.48 | 4.72 | 4.49 | 3.40 | 3.09 | 110 |
| Black Amber | 6.8 | 4.6 | 78 | 2.51 | 4.88 | 2.18 | 2.87 | 2.44 | 3.28 | 4.41 | 3.14 | 3.13 | 2.98 | 2.50 | 4.14 | 1.48 | 4.23 | 4.25 | 3.23 | 3.09 | 105 |
| Sunrise kafir | 8.9 | 6.2 | 68 | 3.60 | 4.04 | 1.35 | 1.95 | 2.49 | 2.18 | 5.18 | 3.42 | 2.66 | 2.64 | 3.15 | 3.83 | 1.24 | 4.78 | 4.53 | 3.14 | 3.09 | 102 |
| Pink kafir | 9.8 | 8.2 | 59 | ..... | 5.43 | 1.53 | 2.74 | 1.92 | 1.54 | 4.37 | 3.29 | 2.36 | 2.37 | 2.94 | 3.51 | 1.28 | 4.98 | 4.76 | 3.07 | 3.11 | 99 |
| Schrock | 9.2 | 6.3 | 52 | 2.26 | 3.45 | 1.41 | 2.33 | 1.98 | 2.36 | 5.42 | 3.16 | 2.12 | 2.24 | 3.04 | 5.14 | 1.11 | 5.09 | 4.65 | 3.05 | 3.09 | 99 |
| Blackhull kafir | 9.8 | 7.7 | 52 | 3.55 | 4.15 | 1.38 | 3.01 | 1.72 | 2.12 | 3.60 | 3.23 | 2.45 | 1.90 | 3.22 | 3.74 | 1.12 | 5.61 | 4.70 | 3.03 | 3.09 | 98 |
| Pink kafir | 9.1 | 6.9 | 59 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.39 | 2.27 | 3.15 | 3.54 | 1.33 | 4.39 | 4.84 | 3.13 | 3.19 | 98 |
| Western Blackhull kafir | 10.1 | 7.8 | 55 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.57 | 2.36 | 2.04 | 3.10 | 3.59 | 1.31 | 5.07 | 4.34 | 3.05 | 3.18 | 96 |
| Dwarf hegari | 12.3 | 6.0 | 52 | 3.14 | 3.53 | 1.90 | ..... | 2.16 | 2.44 | 4.94 | 3.18 | 2.87 | 2.05 | 2.62 | 4.38 | 1.43 | 5.11 | 2.83 | 3.04 | 3.16 | 96 |
| Dawn kafir | 9.4 | 7.4 | 51 | 3.17 | 3.42 | 1.04 | 2.90 | 1.78 | 2.57 | 5.05 | 2.83 | 2.72 | 1.82 | 3.09 | 3.31 | 1.35 | 4.52 | 4.39 | 2.94 | 3.09 | 95 |
| Standard Yellow milo | 11.5 | 7.1 | 70 | 2.45 | 3.40 | ..... | ..... | ..... | 3.11 | 4.90 | 3.01 | 3.06 | 2.45 | 2.75 | 3.95 | 1.17 | 3.54 | 4.40 | 3.18 | 3.36 | 95 |
| Spur feterita | 12.5 | 7.3 | 61 | ..... | ..... | ..... | ..... | ..... | 2.18 | 4.49 | 3.08 | 2.74 | 1.99 | 3.17 | 3.65 | 1.46 | 4.33 | 3.96 | 3.11 | 3.31 | 94 |
| Premo | 14.6 | 11.8 | 51 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.61 | 1.47 | 2.78 | 4.21 | 1.20 | 4.48 | 4.05 | 2.97 | 3.19 | 93 |
| Dwarf Yellow milo | 10.7 | 6.8 | 47 | 2.44 | 4.88 | 1.32 | .66 | 2.11 | 2.74 | 3.91 | 2.79 | 2.93 | 1.88 | 2.87 | 3.60 | .87 | 3.63 | 4.68 | 2.75 | 3.09 | 89 |
| Darso | 10.4 | 8.1 | 52 | ..... | ..... | ..... | ..... | ..... | 2.05 | 3.50 | 2.87 | 2.42 | 1.82 | 2.52 | 4.47 | 1.20 | 4.33 | 4.27 | 2.95 | 3.31 | 89 |
| Red kafir | 8.6 | 6.9 | 57 | 2.93 | 4.02 | 1.21 | 2.60 | 2.04 | 2.03 | 4.22 | 3.05 | 2.35 | 1.77 | 2.57 | 2.95 | 1.10 | 4.09 | 3.97 | 2.73 | 3.09 | 88 |
| Chiltex | 14.2 | 7.0 | 50 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2.37 | 3.58 | .99 | 4.34 | 3.30 | 2.92 | 3.41 | 86 |
| Dwarf White milo | 10.7 | 7.8 | 47 | ..... | ..... | ..... | .61 | 2.10 | 2.54 | 4.20 | 2.75 | 3.19 | 1.98 | 2.47 | 3.42 | .97 | 3.95 | 3.87 | 2.67 | 3.13 | 85 |
| Feterita | 11.0 | 6.6 | 62 | 2.45 | 3.52 | 1.01 | 1.23 | 2.17 | 2.19 | 4.18 | 2.89 | 2.50 | 1.76 | 2.80 | 3.80 | 1.30 | 3.67 | 3.33 | 2.59 | 3.09 | 84 |
| Early White milo | 9.1 | 6.3 | 60 | 2.51 | 4.33 | 1.26 | .26 | 2.01 | 2.40 | 3.99 | 2.39 | 3.17 | 1.89 | 2.67 | 3.35 | 1.17 | 3.42 | 4.14 | 2.60 | 3.09 | 84 |
| Freed | 8.0 | 4.9 | 68 | 2.34 | 3.50 | 1.15 | .86 | 1.28 | 1.96 | 4.40 | 2.45 | 2.87 | 1.69 | 2.33 | 3.18 | 1.50 | 3.54 | 3.46 | 2.43 | 3.09 | 79 |
| Dwarf feterita | 20.4 | 9.7 | 47 | ..... | ..... | ..... | ..... | ..... | 1.12 | 4.21 | 2.66 | 2.47 | 1.13 | 2.50 | 3.97 | 1.02 | 2.95 | 2.51 | 2.45 | 3.31 | 74 |
| Corn (Bloody Butcher) | 18.4 | 14.6 | 62 | 1.11 | 2.62 | 1.18 | .44 | .98 | 2.76 | 4.67 | 2.09 | 3.05 | 1.29 | 1.24 | 3.25 | 1.04 | 3.24 | 3.83 | 2.19 | 3.09 | 71 |

[1] Ratio of yield of a variety to that of the check; check equals 100 percent.

TABLE 5.—*Average length of season and annual and average grain yields of sorghum varieties and 1 variety of corn (included for comparison), 1914–28*

[Yields of each variety compared with those of a composite check derived from the average yields of 10 varieties for the same years in which the variety was grown]

| Variety | Season [1] | Grain yields, per acre (56 pounds per bushel) | | | | | | | | | | | | | | Average of [2]— | | Relative yields [3] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Variety | Check | |
| | *Days* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Percent* |
| Western Blackhull kafir | 111-A | | | | | | | | 36.7 | 21.7 | 25.1 | 46.3 | 42.3 | 0.2 | 64.3 | 64.8 | 37.7 | 28.7 | 131 |
| Spur feterita | 104 | | | | | | 34.9 | 51.6 | 33.1 | 27.4 | 24.1 | 37.5 | 52.3 | 3.3 | 55.4 | 45.7 | 36.5 | 30.1 | 121 |
| Pink kafir | 114-B | | | | | | | | | 15.3 | 26.1 | 45.1 | 37.9 | 0 | 46.6 | 70.0 | 34.4 | 28.7 | 120 |
| Feterita | 100 | 25.7 | 27.0 | 4.5 | 8.2 | 14.3 | 34.1 | 49.3 | 33.1 | 26.8 | 24.1 | 38.1 | 51.7 | 6.8 | 47.3 | 42.1 | 28.9 | 24.1 | 120 |
| Chiltex | 109-A | | | | | | | | | | | 38.3 | 46.4 | 1.3 | 55.2 | 48.2 | 37.9 | 31.5 | 120 |
| Early White milo | 95 | 31.9 | 42.1 | 5.0 | 2.0 | 17.9 | 37.0 | 49.1 | 27.1 | 30.1 | 18.6 | 40.6 | 27.7 | 5.7 | 40.9 | 55.5 | 28.7 | 24.1 | 119 |
| Pink kafir | 114-E | | 47.1 | 0 | 0 | .5 | 24.1 | 55.8 | 43.5 | 16.1 | 22.0 | 28.3 | 38.0 | 0 | 59.1 | 71.4 | 29.0 | 24.4 | 119 |
| Dawn kafir | 112-D | 30.6 | 24.7 | 2.7 | 1.3 | 4.6 | 34.1 | 53.9 | 33.6 | 19.3 | 20.3 | 45.2 | 34.8 | .9 | 50.7 | 60.9 | 27.8 | 24.1 | 115 |
| Western Orange | 104 | 31.4 | 38.5 | 5.2 | 13.9 | 7.3 | 28.9 | 51.1 | 28.9 | 22.4 | 27.0 | 38.7 | 34.1 | 1.0 | 38.9 | 44.3 | 27.4 | 24.1 | 114 |
| Dwarf Yellow milo | 108-A | 14.2 | 40.9 | 2.0 | 2.1 | 1.3 | 41.3 | 46.7 | 28.1 | 30.2 | 15.6 | 40.2 | 39.3 | 1.6 | 39.5 | 68.8 | 27.5 | 24.1 | 114 |
| Dwarf feterita | 106 | | | | | | 20.4 | 56.9 | 33.6 | 33.7 | 19.0 | 37.7 | 59.5 | 3.4 | 40.0 | 35.0 | 33.9 | 30.1 | 113 |
| Dwarf White milo | 106-A | | | | 3.9 | 1.3 | 38.2 | 45.8 | 40.3 | 33.1 | 16.6 | 31.1 | 44.2 | 2.6 | 31.6 | 56.6 | 28.8 | 26.1 | 110 |
| Darso | 113-A | | | | | | 32.2 | 21.1 | 20.9 | 20.9 | 20.9 | 41.5 | 54.6 | 5.4 | 46.1 | 65.7 | 32.9 | 30.1 | 109 |
| Black Amber | 96 | 28.8 | 36.2 | 7.1 | 19.8 | 5.5 | 31.7 | 44.1 | 33.4 | 25.4 | 24.8 | 28.9 | 30.1 | 5.0 | 32.9 | 33.4 | 25.8 | 24.1 | 107 |
| Premo | 112-A | | | | | | | | | 12.2 | 17.7 | 38.6 | 40.2 | 1.1 | 50.0 | 48.6 | 29.8 | 28.7 | 104 |
| Dwarf hegari | 109-D | 11.2 | 40.7 | 0 | | 4.9 | 27.8 | 61.4 | 32.1 | 14.3 | 5.4 | 15.9 | 33.6 | 0 | 73.0 | 40.4 | 25.8 | 25.4 | 102 |
| Schrock | 116-G | 7.5 | 8.5 | 4.8 | .5 | 3.4 | 34.6 | 36.8 | 24.1 | 13.6 | 29.1 | 24.8 | 49.0 | 0 | 59.1 | 63.8 | 24.0 | 24.1 | 100 |
| Red kafir | 111-F | 7.4 | 0 | 0 | 0 | 5.6 | 27.6 | 49.4 | 43.1 | 22.5 | 21.8 | 33.8 | 33.8 | .4 | 53.9 | 60.0 | 24.0 | 24.1 | 100 |
| Sunrise kafir | 111-E | 26.7 | 0 | 0 | .6 | 6.8 | 24.1 | 46.6 | 32.3 | 16.8 | 26.8 | 34.6 | 32.7 | .4 | 50.4 | 54.6 | 23.6 | 24.1 | 98 |
| Leoti Red | 108-A | | | | | | | 39.1 | 28.0 | 24.1 | 27.7 | 32.2 | 31.7 | .5 | 37.0 | 45.4 | 29.5 | 30.1 | 98 |
| Freed | 93 | 25.4 | 29.5 | 7.7 | 4.6 | 7.2 | 22.1 | 52.5 | 30.3 | 25.3 | 23.8 | 23.2 | 21.2 | 12.2 | 29.8 | 35.5 | 23.4 | 24.1 | 97 |
| Standard Yellow milo | 108-A | 13.8 | 13.9 | | | | 34.4 | 45.9 | 30.1 | 23.4 | 19.1 | 31.6 | 38.5 | 1.5 | 33.2 | 49.8 | 27.9 | 28.8 | 97 |
| Early Sumac | 107-B | | | 0 | .9 | 3.5 | 34.2 | 46.4 | 26.7 | 10.6 | 23.3 | 31.0 | 36.8 | 1.6 | 42.9 | 45.9 | 23.4 | 24.2 | 97 |
| Dakota Amber×Sumac | 107 | | | | | | | 47.5 | 26.3 | 18.0 | 19.9 | 31.7 | 31.2 | .3 | 35.7 | 47.5 | 28.7 | 30.1 | 95 |
| Atlas | 120-B | | | | | | | | | | | 11.9 | 25.1 | 0 | 42.9 | 53.0 | 26.6 | 31.5 | 84 |
| Red Amber | 100 | 15.4 | 26.8 | 3.0 | 17.5 | 7.1 | 29.6 | 33.2 | 24.1 | 21.2 | 20.5 | 20.3 | 16.3 | .9 | 30.9 | 32.7 | 20.0 | 24.1 | 83 |
| African "millet" | 116-B | | | | | | | | 23.0 | 5.9 | 10.9 | .6 | 27.7 | 0 | 52.7 | 57.9 | 22.4 | 28.7 | 78 |
| Colman | 110-D | | 8.0 | 0 | .5 | 3.9 | | 45.5 | 17.7 | 14.4 | 20.7 | 31.1 | | | | | 15.8 | 20.5 | 77 |
| Blackhull kafir | 116-G | 9.0 | 12.3 | 0 | 0 | 4.3 | 21.0 | 18.0 | 35.1 | 12.1 | 17.9 | 4.9 | 34.8 | 0 | 53.0 | 56.2 | 18.6 | 24.1 | 77 |
| Sourless | 115-C | | | | | | 18.8 | 0 | 18.2 | 10.9 | 11.6 | 12.0 | 22.3 | 0 | 44.3 | 48.7 | 18.7 | 30.1 | 62 |
| Kansas Orange | 115-G | 3.9 | 6.7 | 0 | 1.1 | 0 | 18.7 | 0 | 14.7 | 9.7 | 12.1 | 10.9 | 25.2 | 0 | 48.6 | 43.2 | 13.0 | 24.1 | 54 |
| Sumac | 114-H | .2 | .8 | | | 0 | 51.4 | 0 | 7.8 | 1.1 | 9.6 | 3.7 | 29.4 | 0 | 44.1 | 42.9 | 14.7 | 27.0 | 54 |
| Garden City Honey | 119-B | | | | | | | | | | 7.7 | .3 | 10.2 | 0 | 13.4 | 22.9 | 9.1 | 30.0 | 30 |
| Corn (Bloody Butcher) | 102-D | 2.8 | 43.8 | 0 | 0 | 0 | 17.4 | 45.9 | 2.9 | 19.3 | 10.1 | 13.4 | 26.6 | 0 | 52.1 | 38.6 | 18.2 | 24.1 | 76 |

[1] The number of years in which the variety designated did not fully mature is indicated by an attached letter as follows: A=1 year; B=2 years; C=3 years, etc.
[2] Average of 10 varieties for the same years in which a variety was grown.
[3] Ratio of yield of a variety to that of the check; check equals 100 percent.

The yields and other agronomic data for the principal sorghum varieties grown during the period 1914–28 are presented in tables 4 and 5. In table 4 the yields of air-dry forage, including heads, are presented by years, together with the average row space per plant and stalk and the average height. In table 5 the grain yields are given by years, together with the average length of season required for maturity. In each table the average yields of each variety are compared with those of a check for the same period. The check is a composite factor derived from the average yields of 10 varieties that were grown in all of the years. These varieties were Black Amber, Red Amber, Western Orange, Kansas Orange, Schrock, Sunrise kafir, Dawn kafir, Dwarf Yellow milo, feterita, and Freed sorghum.

The practice in testing varieties was to use as representative of the variety that strain which was most productive at Hays. This practice resulted in frequent substitutions and changes in the serial numbers. Strains developed by the Division of Cereal Crops and Diseases and the Kansas Agricultural Experiment Station, and new introductions of the Division of Foreign Plant Introduction were substituted for the strains originally included in the tests whenever such new strains appeared more desirable from any standpoint.

The statistical data show many significant differences among the varieties, of which only the principal points may be discussed. In the sorgo group, where tonnage is of the greatest importance, it is noted that the tonnage is in fairly direct proportion to the length of the season required for growth, but the late-maturing varieties suffered more from drought and were often injured by frost prior to normal maturity. Earliness is obtained at the expense of tonnage. In the more favorable seasons, the later and larger varieties can be most advantageously grown for forage. Among seven varieties of approximately equal yields and length of season, there developed wide differences in usefulness, due to qualities not apparent in a statistical study. Red Amber, S.P.I. 17548, for example, was considered the most desirable sorgo for general distribution from the Hays station until its susceptibility to head smut became apparent. Meanwhile Early Sumac (fig. 9) had been developed and was first grown for general distribution in 1922. It at once became popular with the station's seed buyers, and this popularity has continued among those who desire a fairly early sorgo of medium yield and height. To satisfy a demand for a heavier-yielding forage sorgo to be grown in the bottom lands and during the more favorable seasons Kansas Orange was recommended for many years, but apparently the recently developed Sourless × kafir cross, known as Atlas, has taken the place of Orange and has been widely distributed since 1928.

Besides Early Sumac and Atlas, three other sorghums have been grown at Hays for several years for general distribution. These varieties are Dawn kafir, C.I. 904, Pink kafir, C.I. 432, and feterita, C.I. 182-1. The two kafirs, particularly the Pink kafir, have attained wide popularity in the territory surrounding Hays as dual-purpose forage and grain crops. The experimental work suggests Western Blackhull kafir as possibly superior to the Dawn kafir; also Pink kafir, F.C. 9091, as preferable to C.I. 432, in that F.C. 9091 has uniformly juicy stalks, while many stalks in C.I. 432 are pithy. Feterita, C.I. 182-1, is much improved in uniformity and

apparently in germination over the earlier feteritas grown at Hays, and has met the comparatively limited demand there for a drought-resistant grain crop. The recent trend, however, is away from this type and toward shorter-stemmed grain sorghums that are more suited to harvesting with the header or the combine.

Several other varieties have made a good statistical showing, but on account of some defect they have not been recommended. Leoti Red and Colman, apparently related to Red Amber, for example, proved too susceptible to head smut. All the Ambers, as well as Western Orange and Black Dwarf, closely related to the Ambers, are generally considered less satisfactory in forage quality and much more subject to crossing than the Sumac. The standard Blackhull kafirs are not early and drought resistant enough for

FIGURE 9.—Early Sumac sorgo, the variety which replaced Red Amber in the seed distributions of the Hays station.

Hays. The milos are all poor forage and more or less goosenecked. While Dwarf Yellow milo has been widely grown in the Southwest and is much superior to the old standard sorts, it may be replaced in the future by erect-headed crosses. In these tests, there were included a large number of hybrids, often under freak names, such as Fargo, Husser, Duallo, Husserita, Sudan corn, Wonder kafir, and Progressive kafir, which often yielded well but showed some decided weakness, such as lodging, smut susceptibility, nonuniformity, etc. For growers who have heretofore found Freed satisfactory, Modoc, C.I. 905, a Pink kafir-Freed cross, is worth noting as a promising dual-purpose crop for the northwestern fringe of the sorghum belt.

Some of the less-important varieties that were included in the varietal tests for a few years and then discarded because of low yields or other weaknesses are discussed briefly in the following paragraphs.

Dakota Amber, F.C. 1614, grown during the period 1915–20, is a dwarf early strain of Black Amber. It is one of the best varieties in the Dakotas but cannot compete with the later varieties at Hays, making only 81 percent of the check yield of forage and 151 percent of the check in grain. Its average growing season was 87 days, and its average height was 67 inches.

Early Amber, F.C. 8572-2, under test from 1915 to 1919, is a tall, slender strain of Black Amber, having an average height of 79 inches and an average growing season of 88 days. Its relative forage and grain yields were, respectively, 114 percent and 96 percent of the check. It was considered less valuable than no. 7038 because it was not so leafy.

Black Dwarf, F.C. 7085, a short, heavy-stemmed strain with black glumes, was under test from 1914 to 1918. Average height, 64 inches; average growing season, 100 days. Forage yield, 115 percent; grain yield, 108 percent of check.

Coles Evergreen, F.C. 01979, a rather dwarf black-glumed variety, tested at Hays, 1914–18. Average height, 70 inches; average growing season, 102 days. Forage yield, 136 percent; grain yield, 35 percent of check.

Red X, F.C. (commercial) 1479, an important sirup variety in western Arkansas, but not so valuable for forage. Average height, 73 inches; midseason; under test only 3 years, 1915–17. Forage yield, 133 percent; grain yield, 9 percent of check.

McLean, F.P.I. 34985, a tall, rather late, black-glumed variety not adapted to Hays. Under test, 1915–18. Average height, 73 inches; growing season, 104 days, not always maturing. Forage yield, 131 percent; grain yield, 31 percent of check.

Collier, F.C. 1461, a tall, late, black-glumed variety with a small panicle having a short rachis. Under test at Hays, 1915–18. Average height, 75 inches; growing season long, did not mature regularly. Forage yield, 130 percent; grain yield, 11 percent of check.

Dwarf Ashburn, F.C. 8911, a dwarf heavy-stemmed variety with seeds like Sumac, but larger. Under test at Hays, 1918–21. Average height, 50 inches; growing season, 109 days. Forage yield, 88 percent; grain yield, 73 percent of check.

Dawn kafir, C.I. 904, a selection made by A. F. Swanson, of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, has been under test at Hays since 1925. It is about 5 inches taller than C.I. 340 reported in the table and matures in practically the same time. The average forage yield, 1925–28, was 97 percent; average grain yield, 121 percent of the check. This selection was substituted for C.I. 340 on account of superior grain yields.

Dwarf Blackhull kafir, C.I. 330, tested from 1914 to 1918, was found inferior to both of the Dawn selections.

Blackhull kafir, C.I. 204, and Texas Blackhull kafir, C.I. 865, were both tested and proved inferior to Western Blackhull, F.C. 9098.

Reed kafir, C.I. 628, while producing good yields of both forage and grain, was too late and too subject to lodging to be recommended.

Several selections of Pink kafir were made and grown in the variety test for 6 or 7 years, but only F.C. 9091 proved equal to the regular station strain, C.I. 432.

Several hybrids produced by H. Willis Smith were included in the variety test for short periods.[6]

#### DATE-OF-SEEDING TESTS

Five varieties of sorghum were seeded in duplicate $\frac{1}{20}$-acre plots in 40-inch rows at 15-day intervals from May 1 to July 1 during the period 1914–18. The experiment was then discontinued for several years and resumed in 1924 on a different basis. From 1924 to 1928 the entire variety test of about 50 lots was replicated regularly on the three intermediate dates in single $\frac{1}{20}$-acre plots. A supplementary

[6] Mr. Smith, farmer plant breeder, formerly located near Garden City and Kismet, Kans., produced and named the following hybrids. The records of their performance may be found in unpublished reports on file in the Division of Forage Crops and Diseases: Duallo, F.C. 8523, reports for 1914–16; Progressive kafir, F.C. 02249, reports for 1916–19; Husser, F.C. 03198, reports for 1920–23; Husserita, F.C. 9085, reports for 1920–22; Sudan corn, F.C. 03427, reports for 1920–22. The parentage of these hybrids was not always clear in the mind of the originator, but Husserita, a supposed cross between Blackhull kafir and some sorgo, was perhaps the best of the group. It made heavy yields of forage and good grain yields, but was subject to lodging, and the grain did not thresh free from the glumes.

TABLE 6.—*Results from date of seeding tests with five varieties of sorghum, 1914–18 and 1924–28, inclusive*

| Variety and dates of seeding | Forage yields per acre | | | | | | | | | | | | Grain yields per acre | | | | | | | | | | | | Average height | | Average time from seeding to maturity | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1914 | 1915 | 1916 | 1917 | 1918 | 1924 | 1925 | 1926 | 1927 | 1928 | Average for 5 years (1914–18) | Average for 10 years (1914–18, 1924–28) | 1914 | 1915 | 1916 | 1917 | 1918 | 1924 | 1925 | 1926 | 1927 | 1928 | Average for 5 years (1914–18) | Average for 10 years (1914–18, 1924–28) | 5 years (1914–18) | 10 years (1914–18, 1924–28) | 5 years (1914–18) | 10 years (1914–18, 1924–28) |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *In.* | *In.* | *Days* | *Days* |
| Black Amber: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| May 1 | 2.31 | 4.07 | 2.21 | 1.62 | 2.20 | | | | | | 2.48 | | 27.2 | 40.9 | 15.4 | 9.6 | 7.1 | | | | | | 20.0 | | 67 | | 114 | |
| May 15 | 2.51 | 3.59 | 1.83 | 1.76 | 2.65 | 2.63 | 4.26 | 1.19 | 4.16 | 4.11 | 2.47 | 2.87 | 28.8 | 35.1 | 7.0 | 9.8 | 3.6 | 32.7 | 39.5 | 1.0 | 28.9 | 33.2 | 16.9 | 22.0 | 65 | 70 | 107 | 106 |
| June 1 | 2.33 | 4.22 | 1.86 | 1.65 | 2.78 | 2.03 | 4.77 | 1.32 | 4.44 | 4.25 | 2.57 | 2.97 | 26.3 | 37.6 | 6.8 | 11.8 | 7.3 | 27.2 | 36.0 | 7.4 | 41.3 | 35.4 | 18.0 | 23.7 | 67 | 73 | 95 | 97 |
| June 15 | 2.45 | 4.73 | 2.35 | 1.81 | 2.47 | 2.84 | 3.39 | 1.94 | 4.08 | 4.40 | 2.76 | 3.05 | 31.9 | 40.8 | 12.5 | 10.9 | 9.5 | 26.9 | 14.8 | 8.4 | 28.4 | 31.6 | 21.1 | 21.6 | 71 | 77 | 90 | 91 |
| July 1 | 2.46 | 4.44 | 1.89 | 2.05 | 2.29 | 2.45 | 2.37 | 1.70 | 2.75 | 2.93 | 2.63 | 2.53 | 30.0 | 32.1 | 7.7 | 15.7 | 0 | 19.3 | 4.0 | 1.8 | 20.1 | 31.9 | 17.1 | 16.3 | 68 | 72 | 88 | 88 |
| Red Amber: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| May 1 | 2.87 | 4.76 | 1.12 | 2.00 | 2.24 | | | | | | 2.60 | | 11.7 | 29.6 | 0 | 10.9 | 4.3 | | | | | | 11.3 | | 70 | | 121 | |
| May 15 | 2.93 | 4.32 | 1.26 | 1.86 | 1.91 | 2.82 | 3.77 | 1.17 | 4.43 | 4.50 | 2.46 | 2.90 | 15.4 | 20.5 | 0 | 10.2 | 0 | 20.6 | 16.6 | 0 | 25.7 | 33.2 | 9.2 | 14.2 | 65 | 70 | 111 | 110 |
| June 1 | 3.81 | 4.82 | 1.81 | 2.34 | 2.07 | 2.46 | 4.17 | 1.48 | 5.07 | 4.31 | 2.97 | 3.23 | 19.3 | 16.6 | 0 | 11.1 | 0 | 18.6 | 21.5 | 1.4 | 35.4 | 37.0 | 9.4 | 16.1 | 66 | 72 | 101 | 102 |
| June 15 | 3.48 | 5.50 | 1.86 | 2.60 | 1.73 | 3.36 | 3.18 | 2.04 | 3.90 | 4.44 | 3.03 | 3.21 | 15.9 | 25.8 | 0 | 10.5 | 3.6 | 21.7 | 10.7 | 1.5 | 31.6 | 27.9 | 11.2 | 14.9 | 68 | 73 | 95 | 96 |
| July 1 | 3.64 | 4.54 | 1.70 | 2.87 | 1.95 | 3.30 | 2.97 | 2.31 | 3.00 | 2.82 | 2.94 | 2.91 | 23.9 | 9.5 | 0 | 5.2 | 0 | 16.1 | 2.8 | 0 | 23.0 | 21.5 | 7.7 | 10.2 | 65 | 69 | 95 | 92 |
| Freed: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| May 1 | 2.30 | 3.06 | 1.14 | .99 | .45 | | | | | | 1.59 | | 28.5 | 27.3 | 12.4 | 6.3 | 4.1 | | | | | | 15.7 | | 69 | | 115 | |
| May 15 | 2.34 | 2.95 | 1.01 | 1.35 | 1.42 | 2.48 | 3.54 | 1.73 | 3.36 | 3.06 | 1.81 | 2.32 | 25.4 | 23.1 | 9.6 | 5.2 | 15.2 | 26.5 | 19.3 | 12.0 | 23.6 | 30.0 | 15.7 | 19.0 | 67 | 64 | 106 | 104 |
| June 1 | 2.22 | 3.43 | 1.21 | 1.44 | 1.57 | 2.48 | 3.09 | 1.23 | 3.99 | 3.20 | 1.97 | 2.39 | 26.5 | 22.3 | 11.6 | 7.3 | 13.9 | 21.8 | 19.8 | 10.0 | 31.6 | 35.9 | 16.3 | 20.1 | 68 | 66 | 94 | 95 |
| June 15 | 2.46 | 3.83 | 1.54 | .93 | 1.80 | 2.03 | 2.91 | 1.53 | 3.27 | 4.13 | 2.11 | 2.44 | 31.5 | 26.4 | 14.5 | 7.0 | 10.7 | 21.2 | 27.6 | 14.6 | 34.3 | 40.7 | 18.0 | 22.9 | 67 | 68 | 88 | 89 |
| July 1 | 2.43 | 3.39 | 1.37 | 1.15 | 1.92 | 2.15 | 2.61 | 1.51 | 2.85 | 1.52 | 2.05 | 2.09 | 27.4 | 20.9 | 14.3 | 6.4 | 9.8 | 27.9 | 18.2 | 13.7 | 26.5 | 14.3 | 15.8 | 17.9 | 66 | 66 | 83 | 86 |
| Feterita: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| May 1 | 1.75 | 3.94 | 1.36 | 1.30 | .70 | | | | | | 1.81 | | 16.8 | 29.6 | 9.8 | 8.6 | 6.3 | | | | | | 14.2 | | 60 | | 119 | |
| May 15 | 2.24 | 3.21 | 1.03 | 1.66 | 1.55 | 2.57 | 3.53 | 1.33 | 3.09 | 3.18 | 1.94 | 2.34 | 18.3 | 32.5 | 7.3 | 12.7 | 8.8 | 39.3 | 38.8 | 7.3 | 44.5 | 39.6 | 15.9 | 24.9 | 56 | 57 | 110 | 110 |
| June 1 | 3.18 | 4.26 | 1.15 | 1.27 | 1.70 | 2.93 | 3.44 | 1.19 | 4.94 | 3.35 | 2.31 | 2.74 | 28.1 | 42.6 | 3.6 | 10.4 | 6.8 | 33.8 | 51.3 | 3.0 | 56.8 | 45.5 | 18.3 | 28.2 | 54 | 57 | 101 | 102 |
| June 15 | 2.44 | 2.48 | .87 | 1.60 | 1.79 | 2.90 | 4.44 | 1.37 | 2.97 | 3.45 | 1.84 | 2.43 | 19.4 | 19.7 | 5.9 | 11.8 | 8.9 | 41.3 | 64.9 | 10.2 | 40.7 | 41.3 | 13.1 | 26.4 | 54 | 58 | 94 | 95 |
| July 1 | 2.86 | 2.78 | .98 | 1.52 | 1.77 | 2.03 | 2.55 | 1.14 | 3.02 | 2.16 | 1.98 | 2.08 | 21.3 | 12.9 | 3.9 | 5.0 | 0 | 35.4 | 36.2 | 14.8 | 33.2 | 36.9 | 8.6 | 20.0 | 53 | 59 | 97 | 94 |
| Dawn kafir: | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| May 1 | 3.08 | 4.35 | .90 | 2.14 | .22 | | | | | | 2.14 | | 7.2 | 29.1 | 4.3 | 1.8 | 3.0 | | | | | | 9.1 | | 50 | | 129 | |
| May 15 | 3.55 | 5.09 | 1.02 | 2.44 | .76 | 2.37 | 3.54 | 1.06 | 4.62 | 4.74 | 2.57 | 2.92 | 9.0 | 62.9 | 3.2 | 1.8 | 5.9 | 36.1 | 39.8 | 0 | 49.2 | 67.0 | 16.6 | 27.5 | 50 | 50 | 120 | 120 |
| June 1 | 3.29 | 6.10 | .99 | 2.39 | 1.62 | 3.84 | 3.24 | 1.30 | 3.78 | 4.26 | 2.88 | 3.08 | 7.4 | 65.1 | 1.3 | 0 | 10.2 | 47.9 | 38.1 | 0 | 44.5 | 57.3 | 16.8 | 27.2 | 49 | 51 | 111 | 112 |
| June 15 | 3.55 | 4.46 | 1.29 | 2.43 | 1.70 | 3.05 | 3.15 | 1.70 | 5.16 | 4.17 | 2.69 | 3.07 | 19.3 | 42.7 | 0 | 0 | 8.4 | 51.6 | 26.4 | 2.7 | 58.4 | 58.4 | 14.1 | 26.8 | 48 | 52 | 108 | 108 |
| July 1 | 2.38 | 4.41 | 1.69 | 2.78 | 1.77 | 3.28 | 2.73 | 1.70 | 4.35 | 2.33 | 2.61 | 2.74 | 0 | 9.6 | 0 | 0 | 0 | 0 | 3.2 | .9 | 42.1 | 28.2 | 1.9 | 8.4 | 46 | 50 | 95 | 96 |

test of numerous varieties was also conducted in single 2-row plots of smaller area seeded on July 1, 1923–28. The results thus available for 10 years with five of the varieties are presented in table 6.

Land for the entire experiment was always prepared in advance of the first seeding. The later the seeding, therefore, the greater the preliminary opportunity to kill weeds, conserve moisture, and secure ideal tilth. The experiments were conducted with the idea of getting the maximum possible results from each date. It seems that the yields thus obtained for different dates were more nearly equal and those from the extreme dates more satisfactory than they would have been if seed-bed preparation had been in accord with the usual farm practice of listing at seeding time, or perhaps disking a few days ahead of the lister. All the plots were handled on a weed-free basis by hoeing out such weeds as machinery could not reach. Much hand weeding was required with the May 1 seedings, considerable in the May 15 plots, a little for June 1 and 15, and a minimum amount in the July 1 seeding. The number of cultivations after seeding usually varied from 3 to 4 for the earliest dates down to 2 for June 15 and 1 for July 1. In about half the seasons the June 15 plots would have done very well with 1 cultivation and the July 1 plots with none at all.

Fairly good stands were usually obtained, regardless of the date or the variety, because enough choice seed was put on to allow for probable losses. When a stand was too thick, the plots were thinned to 6 or 8 inches row space per plant when a few inches tall. May seedings required an average of 14 days to come up, June seedings 7 days, and July 1 seedings only 5 days. Cold wet spells of 10 days or more were often encountered up to as late as June 20, and, in some cases, a period in May was therefore more favorable than in June for establishing sorghums.

A sharp decline in the number of days from seeding to maturity is noted as the date of seeding becomes later, but the average heights of the plants fluctuate but little.

It was concluded that sorghums could be seeded satisfactorily over a wide range of time, especially for forage production, but that for practical purposes seeding should usually be completed within the period of May 15 to June 15. For grain, the standard varieties should usually be seeded within the first half of this period, but early sorts, such as feterita and Freed, often give the best results from June 15 seeding. The possibilities shown for July 1 seeding are of great interest from the catch-crop standpoint, where an earlier seeding has failed and the land is in good condition. Freed, when seeded July 1, matured every year over an 11-year period.

Data obtained on date of seeding during 1924–28, by replicating the sorghum variety tests at 15-day intervals from May 15 to July 1, are presented in table 7. As each year's work included but a single replication of the varieties on each date, the data are presented by 5-year averages rather than by individual years. The July 1 seedings were supplementary to the main experiment and did not include the entire list of varieties. This table permits a broad comparison of results among variety groups of different seasonal length, but the general conclusions reached are similar to those already discussed in the 10-year test of five varieties.

TABLE 7.—*Average yields from different dates of seeding of sorghum varieties and one variety of corn (included for comparison), 1924–28*

| Varieties, with serial numbers, grouped according to length of season | Season, average of first three dates | Average yields of forage and grain per acre from seeding of— | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | May 15 | | June 1 | | June 15 | | July 1 | |
| | | Forage | Grain | Forage | Grain | Forage | Grain | Forage | Grain |
| Group 1—season 96 to 105 days: | *Days* | *Tons* | *Bu.* | *Tons* | *Bu.* | *Tons* | *Bu.* | *Tons* | *Bu.* |
| Black Amber, F.C. 7038 | 99 | 3.27 | 27.0 | 3.36 | 29.3 | 3.33 | 21.8 | 2.44 | 15.4 |
| Red Amber, S.P.I. 17548 | 102 | 3.34 | 19.2 | 3.50 | 22.8 | 3.38 | 18.6 | 2.88 | 12.7 |
| Early Sumac, F.C. 6611 | 105 | 3.50 | 29.1 | 3.48 | 32.2 | 3.74 | 33.6 | 3.04 | 13.1 |
| Early White milo, F.C. 5886 | 99 | 3.24 | 32.1 | 2.95 | 35.7 | 2.67 | 34.4 | 2.46 | 27.8 |
| Feterita, C.I. 182-1 | 103 | 2.74 | 33.9 | 3.17 | 38.1 | 3.03 | 39.7 | 2.19 | 31.3 |
| Freed, F.C. 9033 | 96 | 2.83 | 22.3 | 2.80 | 23.8 | 2.77 | 27.1 | 2.13 | 20.1 |
| Average | 101 | 3.15 | 27.3 | 3.21 | 30.3 | 3.15 | 29.2 | 2.52 | 20.1 |
| Yield ratios (May 15=100) percent | | 100 | 100 | 102 | 111 | 100 | 107 | 80 | 74 |
| Group 2—season 106 to 110 days: | | | | | | | | | |
| Leoti Red, F.C. 6610 | 109 | 3.92 | 31.5 | 4.01 | 29.1 | 3.91 | 27.4 | 2.91 | 8.6 |
| Western Orange, F.C. 9073 | 106 | 3.53 | 31.0 | 3.53 | 32.2 | 3.83 | 30.9 | 3.23 | 12.3 |
| Dakota Amber×Sumac, F.C. 8574 | 108 | 3.84 | 31.2 | 3.74 | 27.1 | 4.01 | 29.5 | ------ | ------ |
| Early Pink kafir, F.C. 9089 | 110 | 2.85 | 37.1 | 3.04 | 37.6 | 2.72 | 32.9 | 2.22 | 20.6 |
| Dwarf Yellow milo, C.I. 332 | 109 | 3.29 | 38.1 | 3.32 | 42.6 | 2.77 | 33.0 | 2.22 | 12.7 |
| Standard Yellow milo, C.I. 234 | 110 | 3.37 | 32.9 | 3.11 | 31.7 | 3.00 | 28.2 | ------ | ------ |
| Dwarf White milo, F.C. 8927 | 109 | 3.02 | 35.3 | 2.68 | 33.1 | 3.10 | 31.2 | 2.05 | 13.6 |
| Spur feterita, F.C. 6601 | 108 | 3.04 | 34.3 | 3.59 | 42.5 | 3.32 | 39.6 | 2.61 | 26.0 |
| Dwarf feterita, F.C. 9076 | 109 | 2.62 | 34.2 | 2.51 | 35.4 | 2.64 | 35.7 | 1.81 | 21.2 |
| Red Amber×feterita, F.C. 9121 | 110 | 3.81 | 30.8 | 3.50 | 27.3 | 3.84 | 26.1 | ------ | ------ |
| Chiltex, F.C. 8917 | 109 | 2.65 | 33.2 | 2.98 | 38.5 | 3.10 | 41.9 | ------ | ------ |
| Average | 109 | 3.27 | 33.6 | 3.27 | 34.3 | 3.29 | 32.4 | 2.44 | 16.4 |
| Yield ratios (May 15=100) percent | | 100 | 100 | 100 | 102 | 101 | 96 | 77 | 48 |
| Group 3—season 111 to 115 days: | | | | | | | | | |
| Pink kafir, C.I. 432 | 115 | 3.41 | 36.6 | 3.51 | 40.9 | 3.55 | 40.6 | 3.19 | 21.7 |
| Red kafir, C.I. 6608 | 114 | 2.82 | 37.0 | 2.90 | 35.7 | 3.08 | 36.5 | ------ | ------ |
| Dawn kafir, C.I. 340 | 114 | 3.27 | 38.4 | 3.28 | 37.6 | 3.45 | 39.5 | 2.88 | 14.9 |
| Sunrise kafir, C.I. 472 | 115 | 3.67 | 35.0 | 3.17 | 30.8 | 3.68 | 37.8 | ------ | ------ |
| Western Blackhull kafir, F.C. 9098 | 114 | 3.50 | 44.0 | 3.53 | 43.1 | 3.42 | 43.6 | 2.75 | 12.6 |
| Dwarf hegari, F.C. 9078 | 113 | 3.18 | 36.8 | 2.86 | 28.3 | 3.78 | 32.6 | ------ | ------ |
| Premo, F.C. 8929 | 113 | 3.31 | 38.3 | 3.35 | 39.5 | 3.36 | 29.2 | ------ | ------ |
| Weskan, F.C. 9126 | 112 | 2.76 | 38.9 | 2.95 | 38.3 | 3.59 | 45.2 | ------ | ------ |
| Darso, F.C. 6606 | 114 | 3.22 | 43.3 | 3.19 | 42.8 | 3.65 | 41.9 | 2.68 | 10.4 |
| Average | 114 | 3.24 | 38.7 | 3.19 | 37.4 | 3.51 | 38.5 | 2.88 | 14.9 |
| Yield ratios (May 15=100) percent | | 100 | 100 | 98 | 97 | 108 | 99 | 86 | 37 |
| Group 4—season 116 to 120 days: | | | | | | | | | |
| Kansas Orange, F.C. 9108 | 118 | 4.37 | 34.3 | 4.04 | 23.2 | 4.24 | 19.2 | 3.45 | 0 |
| Sourless, F.C. 9074 | 117 | 4.25 | 31.5 | 3.94 | 26.0 | 4.25 | 18.9 | 3.65 | 0 |
| Blackhull kafir×Sourless, F.C. 9112 (Atlas 1928) | 120 | 4.36 | 32.8 | 4.05 | 24.2 | 4.26 | 22.7 | ------ | ------ |
| African millet, F.C. 9111 | 119 | 4.11 | 31.1 | 4.09 | 29.2 | 4.29 | 23.1 | ------ | ------ |
| Garden City honey, F.C. 9105 | 119 | 4.25 | 10.2 | 3.92 | 9.7 | 3.96 | 8.2 | ------ | ------ |
| Sumac (standard), F.C. 9130 et al | 117 | 4.06 | 28.1 | 4.32 | 25.1 | 4.33 | 18.8 | 3.53 | 6.8 |
| Pink kafir, F.C. 9091 | 117 | 3.55 | 43.7 | 3.52 | 40.2 | 3.28 | 35.9 | ------ | ------ |
| Reed kafir, C.I. 628 | 116 | 3.40 | 36.4 | 3.62 | 38.6 | 3.74 | 33.7 | ------ | ------ |
| Blackhull kafir, C.I. 204 | 116 | 3.47 | 38.1 | 3.56 | 39.6 | 3.83 | 38.8 | ------ | ------ |
| Blackhull kafir (standard), F.C. 9119 | 120 | 3.59 | 33.2 | 3.64 | 28.4 | 3.81 | 27.8 | 2.73 | 0 |
| Schrock, F.C. 1481 | 119 | 3.65 | 43.8 | 3.65 | 41.8 | 4.13 | 32.4 | 3.46 | 10.2 |
| Average | 118 | 3.91 | 33.0 | 3.85 | 29.6 | 4.01 | 25.4 | 3.36 | 3.4 |
| Yield ratios (May 15=100) percent | | 100 | 100 | 98 | 90 | 103 | 77 | 84 | 10 |
| Corn (Bloody Butcher) | 109 | 2.31 | 20.2 | 2.52 | 31.5 | 2.73 | 26.8 | ------ | ------ |

TABLE 8.—*Results of spacing experiments with feterita and Red Amber sorghum, 1914–18*

[Rows 40 inches apart except as indicated]

| Variety and spacing between plants | Average row space per stalk | Average height of plants | Forage yields per acre | | | | | | Grain yields per acre | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1914 | 1915 | 1916 | 1917 | 1918 | Average | 1914 | 1915 | 1916 | 1917 | 1918 | Average |
| Red Amber: | *Inches* | *Inches* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Bushels* | *Bushels* | *Bushels* | *Bushels* | *Bushels* | *Bushels* |
| 2 inches | 1.9 | 66 | 3.69 | 4.98 | 1.44 | 2.89 | 2.77 | 3.15 | 9.9 | 27.1 | 0.6 | 10.7 | 2.7 | 10.2 |
| 4 inches | 3.4 | 66 | 3.41 | 4.41 | 1.07 | 2.23 | 2.75 | 2.77 | 15.1 | 29.4 | .9 | 6.4 | 4.2 | 11.2 |
| 6 inches | 3.6 | 67 | 3.57 | 4.40 | 1.00 | 2.26 | 2.74 | 2.79 | 18.3 | 28.2 | 1.2 | 8.4 | 3.4 | 11.9 |
| 8 inches | 4.2 | 68 | 3.66 | 3.78 | 1.08 | 1.89 | 2.62 | 2.61 | 23.2 | 24.3 | 1.8 | 8.0 | 4.0 | 12.3 |
| 12 inches | 4.7 | 70 | 3.16 | 3.68 | 1.44 | 1.78 | 2.66 | 2.54 | 22.1 | 26.3 | 2.0 | 8.2 | 7.6 | 13.2 |
| Feterita: | | | | | | | | | | | | | | |
| 4 inches [1] | | | | 2.18 | 1.36 | 1.52 | 1.98 | 1.76 | | 22.1 | 11.4 | 11.4 | 16.5 | 15.4 |
| Do | 3.1 | 60 | 3.11 | 3.59 | 1.58 | 2.17 | 2.51 | 2.59 | 24.6 | 34.9 | 5.0 | 17.5 | 12.1 | 18.8 |
| 8 inches | 4.3 | 60 | 3.16 | 3.28 | 1.43 | 1.82 | 2.45 | 2.43 | 28.9 | 33.9 | 10.5 | 13.2 | 19.2 | 21.1 |
| 12 inches | 4.9 | 58 | 3.09 | 2.98 | 1.09 | 1.95 | 2.53 | 2.33 | 29.6 | 26.9 | 6.4 | 15.0 | 16.8 | 18.9 |
| 16 inches | 5.9 | 58 | 2.95 | 2.81 | .92 | 1.71 | 2.45 | 2.17 | 28.3 | 22.1 | 5.4 | 15.0 | 18.2 | 17.8 |
| 24 inches | 7.2 | 57 | 2.25 | 2.59 | .91 | 1.37 | 2.18 | 1.86 | 21.5 | 18.4 | 6.1 | 10.4 | 13.9 | 14.1 |

[1] Rows 80 inches apart.

### SPACING EXPERIMENTS IN CULTIVATED ROWS

Spacing experiments in cultivated rows were conducted with Red Amber, S.P.I. 17548, and with common feterita during the period 1914–18. Further experiments on a different basis were begun with Pink kafir, C.I. 432, and continued from 1919 to 1928, inclusive. Actual spacings were almost always identical or very close to those outlined throughout both series of tests. To secure such stands, all plots were seeded relatively thick and were thinned by hand when the plants were a few inches tall.

Data for the experiments from 1914 to 1918 are assembled in table 8. They show that forage yields increased regularly with the thickness of the stands. The average yields and the quality of Red Amber sorgo seed were both best with the thinner spacings, though not varying much within the limits of 4 to 12 inches of row space. Feterita grain yields were largest at 8 inches of row space in the 40-inch rows.

The results with Pink kafir spacing tests (fig. 10) are given in table 9. Alternate 40- and 80-inch rows were a new feature here, involving a

FIGURE 10.—Spacing test with Pink kafir. In the foreground alternate 40- and 80-inch spaces with plants 16 inches apart in the rows are shown.

wide space on one side of each row and the regular interval on the other. The four respective rates of spacing in these rows and in the regular 80-inch rows provided for the same number of plants per acre as in the 40-inch rows. The results were unusually consistent throughout this experiment, but in interpreting them consideration must be given to the fact that the data, except in 1926, were obtained under a favorable series of soil and seasonal conditions. Regular 40-inch rows led in forage yields by about 10 percent over the alternate 40- and 80-inch rows and by about 20 percent over the 80-inch rows. The spread in seed yields among the three methods was much narrower but in the same order. In each of the three methods the yields of both forage and grain were in direct ratio to the closeness of spacing within the row.

TABLE 9.—*Results of spacing experiments with Pink kafir, 1919–28, inclusive*

| Row and plant spacings | Average row space per stalk | Average height of plants | Forage yields per acre | | | | | | | | | | | Grain yields per acre | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Average | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Average |
| | *In.* | *In.* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* |
| 40-inch rows: | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 inches | 5.7 | 59 | 3.27 | 4.13 | 4.36 | 3.19 | 2.73 | 2.83 | 3.44 | 1.06 | 4.93 | 4.46 | 3.44 | 39.3 | 49.6 | 58.1 | 34.8 | 27.7 | 30.3 | 33.6 | 0 | 62.1 | 67.1 | 40.3 |
| 12 inches | 8.4 | 57 | 2.95 | 3.56 | 3.97 | 2.58 | 2.27 | 3.18 | 3.02 | 1.11 | 4.73 | 3.63 | 3.10 | 45.7 | 32.9 | 52.9 | 29.9 | 29.8 | 33.9 | 35.9 | 0 | 52.1 | 53.8 | 36.7 |
| 18 inches | 11.2 | 55 | 2.63 | 3.52 | 3.40 | 2.08 | 1.91 | 3.25 | 3.86 | 1.39 | 3.67 | 2.86 | 2.86 | 35.7 | 31.8 | 41.9 | 21.2 | 28.1 | 29.6 | 47.5 | 0 | 40.4 | 41.6 | 31.8 |
| 24 inches | 13.9 | 55 | 2.50 | 2.98 | 3.13 | 2.19 | 1.78 | 3.08 | 2.76 | 1.20 | 3.24 | 2.40 | 2.53 | 29.1 | 33.2 | 43.5 | 26.0 | 26.3 | 30.5 | 36.4 | 0 | 36.8 | 34.8 | 29.7 |
| Alternate 40- and 80-inch rows: | | | | | | | | | | | | | | | | | | | | | | | | |
| 4 inches | 4.1 | 61 | 2.68 | 3.80 | 4.13 | 2.88 | 2.44 | 2.60 | 2.69 | 1.10 | 4.19 | 3.89 | 3.04 | 40.8 | 50.4 | 56.3 | 33.7 | 30.8 | 31.3 | 26.9 | 0 | 55.2 | 59.6 | 38.5 |
| 8 inches | 6.3 | 60 | 2.68 | 2.88 | 3.49 | 2.41 | 2.15 | 2.77 | 2.85 | 1.16 | 3.82 | 3.35 | 2.75 | 44.8 | 33.9 | 49.2 | 33.0 | 30.7 | 35.6 | 36.6 | 0 | 48.6 | 48.6 | 36.1 |
| 12 inches | 8.0 | 58 | 2.48 | 3.27 | 3.28 | 1.95 | 1.81 | 2.73 | 2.84 | 1.31 | 3.10 | 2.65 | 2.54 | 37.0 | 32.3 | 45.8 | 25.9 | 28.4 | 32.6 | 37.6 | 0 | 38.9 | 38.0 | 31.7 |
| 16 inches | 10.1 | 57 | 2.12 | 2.71 | 3.10 | 1.85 | 1.52 | 2.56 | 2.32 | 1.33 | 2.62 | 2.13 | 2.23 | 30.4 | 31.6 | 44.2 | 25.9 | 24.0 | 30.5 | 31.5 | 0 | 32.0 | 32.0 | 28.2 |
| 80-inch rows: | | | | | | | | | | | | | | | | | | | | | | | | |
| 3 inches | 3.3 | 63 | 2.47 | 3.49 | 3.93 | 2.58 | 2.13 | 2.28 | 2.65 | 1.35 | 3.89 | 3.22 | 2.80 | 38.9 | 46.1 | 53.5 | 31.9 | 26.1 | 29.9 | 39.0 | 0 | 52.1 | 47.3 | 36.5 |
| 6 inches | 5.3 | 62 | 2.26 | 2.84 | 3.21 | 2.26 | 1.92 | 2.22 | 2.34 | 1.21 | 3.36 | 2.99 | 2.46 | 36.8 | 34.6 | 46.3 | 31.8 | 30.4 | 33.5 | 29.6 | 0 | 41.3 | 41.8 | 32.6 |
| 9 inches | 6.8 | 60 | 2.13 | 2.96 | 3.10 | 1.94 | 1.45 | 2.27 | 2.91 | 1.32 | 2.67 | 2.26 | 2.30 | 32.7 | 32.3 | 46.0 | 26.6 | 24.2 | 31.1 | 38.6 | 0 | 33.4 | 32.9 | 29.8 |
| 12 inches | 8.7 | 59 | 1.85 | 2.39 | 3.00 | 1.73 | 1.20 | 2.41 | 1.99 | 1.24 | 2.59 | 2.04 | 2.04 | 28.0 | 30.2 | 45.3 | 24.7 | 18.9 | 31.4 | 25.1 | 0 | 29.5 | 31.8 | 26.5 |

### RATE OF SEEDING FOR HAY PRODUCTION IN CLOSE DRILLS

Tests of five rates of seeding Red Amber sorgo, S.P.I. 17548, in close drills, were conducted from 1914 to 1918. The yields obtained (table 10) were surprisingly uniform among the different rates, but differences in quality were more noticeable. The 15-pound seedings usually produced the tallest and coarsest plants and were least affected by drought. At the other extreme, the 60-pound and 75-pound seedings were finest stemmed and shortest but were too much inclined to dry up prematurely. When the quality of the hay was considered, as well as the yields, rates of 30 and 45 pounds were the most desirable in this experiment, which encountered droughty conditions in 4 of the 5 seasons (fig. 11).

FIGURE 11.—Sorgo sown with a wheat drill at the rate of 45 pounds per acre, producing abundant hay crops

TABLE 10.—*Hay yields of Red Amber sorgo seeded at different rates in close drills 1914–18*

| Rate seeded per acre (pounds) | Row width | Yields of hay per acre | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1914 | 1915 | 1916 | 1917 | 1918 | Average |
| | *Inches* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| 15 | 16 | 4.24 | 6.81 | 1.79 | 2.99 | 3.25 | 3.82 |
| 30 | 8 | 3.98 | 6.91 | 1.83 | 2.67 | 3.16 | 3.71 |
| 45 | 8 | 3.74 | 7.16 | 1.84 | 2.65 | 2.52 | 3.58 |
| 60 | 8 | 3.62 | 7.13 | 1.82 | 3.10 | 2.53 | 3.64 |
| 75 | 8 | 3.75 | 7.17 | 1.64 | 2.59 | 3.17 | 3.66 |

### VARIETY TESTS IN CLOSE DRILLS FOR HAY PRODUCTION

A few leading sorghums were compared in close drills for hay production during four or more years of the period 1922–28. Red Amber had already been grown in close drills since 1914, and 15 years' data on this variety are available which are presented in detail on page 48 in comparison with Sudan grass and millet.

The normal date of seeding was early in June, but two replications were often made about 2 weeks apart. The rate of seeding varied slightly with the season and the variety, but was usually from 2 to 3 pecks to the acre.

The yields for this experiment are presented in table 11. The relative yields in the last column of this table are considered a fair index of the capacity of the varieties. Kansas Orange led by a good margin, and Freed was definitely lower than the others. It is probable, however, that other factors, such as foliage, juiciness, earliness, height, coarseness, and lodging, are more important than the yield differences here shown.

FIGURE 12.—Early Sumac sorgo hay in stack. The Hays station has found that seeding sorgo in close drills is the best method of insuring an adequate supply of forage for the winter months.

TABLE 11.—*Yields of sorghum varieties seeded in close drills for hay production, 1922–28*

| Variety and serial no. | Forage yields per acre | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Average of— | |
| | | | | | | | | Variety | Relative [1] |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Percent* |
| Red Amber, S.P.I. 17548 | 3.51 | 2.32 | 2.65 | 4.42 | 1.21 | 4.63 | 4.68 | 3.35 | 100 |
| Leoti Red, F.C. 6610 | ..... | 2.29 | 3.40 | 4.91 | 1.49 | 4.58 | ..... | 3.33 | 109 |
| Early Sumac, F.C. 6611 | ..... | 2.48 | 2.96 | 4.79 | 1.47 | 4.76 | 4.67 | 3.52 | 106 |
| Pink kafir, C.I. 432 | ..... | ..... | ..... | 4.53 | 1.29 | 4.88 | 4.17 | 3.72 | 99 |
| Kansas Orange, F.C. 9108 | ..... | ..... | 4.21 | 5.29 | 1.34 | 5.05 | ..... | 3.97 | 123 |
| Freed, F.C. 9033 | 2.98 | 2.36 | 2.13 | 2.85 | 1.45 | 3.96 | 3.00 | 2.68 | 80 |

[1] The average yield of Red Amber for the same period of years covered by any other variety is used as 100 percent.

The medium-early sorgos, Early Sumac, Red Amber, and Leoti Red, appear best suited for close-drilled hay production under normal conditions. Early Sumac is perhaps the most favored for this purpose. The Hays station has grown Early Sumac hay extensively in recent years (fig. 12) and has found it particularly valuable in the

wintering of beef cattle. The hay is fine and leafy, very palatable, and is consumed with a minimum of waste, even when carried over in stacks until the second winter. Pink kafir is rather coarse for hay if seeded thinly enough to permit a normal development, but it carries heavy foliage and gives good results in wintering cattle. Kansas Orange is inclined to become coarse and to lodge in a wet season and is relatively low in drought resistance. Freed is suited for very late seeding, for the shorter season of extreme northwestern Kansas, for relatively adverse conditions, and where grain is desired with the hay.

### VARIETY TESTS IN CLOSE DRILLS FOR GRAIN PRODUCTION

The possibility of producing sorghum grain economically from fine-stemmed plants and handling the crop with small-grain equipment appealed particularly to the late C. V. Piper, formerly in charge of the Division of Forage Crops and Diseases. He felt that special sorghums might be bred for this purpose, possibly by crossing Sudan grass with a grain sorghum. A hybrid, F.C. 03194, between Sudan grass and Freed, was sent to Hays and grown in 8-inch and in 16-inch drills in comparison with regular Freed in 1922 and 1923. Yields of this hybrid were disappointing, however, and the later experiments were continued mainly with Freed, Dwarf Freed, and feterita. These varieties were chosen because it was at once evident that maximum drought resistance, a quality associated usually with earliness, would be required if the sorghum were to head and fill well under close-drilled conditions.

TABLE 12.—*Yields of sorghums seeded in close drills for grain production, 1922–28*

| Variety and serial no. | Row width | Rate sown | Grain yields per acre | | | | | | | Average of— | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Variety | Relative [1] |
| | *In.* | *Lb.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Bu.* | *Pct.* |
| Freed×Sudan grass, F.C. 03194 | 8 | 30 | 14.0 | 10.0 | | | | | | 12.0 | 63 |
| | 16 | 15 | 18.8 | 17.9 | | | | | | 18.4 | 96 |
| Freed, F.C. 9033 | 8 | 42 | | | 14.9 | 15.7 | | | | 15.3 | 67 |
| | 8 | 28 | 15.5 | 14.7 | 20.5 | 18.9 | 0.7 | 33.7 | 10.3 | 16.3 | 90 |
| | 8 | 14 | | | 21.8 | 22.9 | | | | 22.4 | 97 |
| | 8 | 7 | | | 21.5 | 22.3 | | | | 21.9 | 96 |
| | 16 | [2] 14 | 19.3 | 27.0 | 33.7 | 18.6 | .9 | 30.9 | 8.2 | 19.8 | 110 |
| | 40 | 3 | 25.3 | 23.8 | 30.3 | 30.4 | 12.2 | 29.8 | 35.5 | 26.8 | 148 |
| Dwarf Freed, C.I. 971 | 8 | 28 | | | | 23.6 | .4 | 44.0 | 13.1 | 20.3 | 133 |
| | 16 | 14 | | | | | .4 | 44.6 | 10.3 | 18.4 | 131 |
| | 40 | 3 | | | | 31.7 | 12.1 | 34.1 | 42.3 | 30.1 | 197 |
| Feterita [3] | 8 | 20 | | | | 30.9 | 2.6 | 33.2 | 23.6 | 22.6 | 148 |
| | 16 | 40 | | | | | 2.3 | 32.4 | 18.7 | 17.8 | 126 |
| | 40 | 4 | 26.8 | 24.1 | 38.7 | 51.7 | 6.8 | 47.3 | 42.1 | 33.9 | 188 |

[1] The average of yields for Freed, F.C. 9033, in the same years in 8-inch drills at 28 pounds and in 16-inch rows at 7 or 14 pounds of seed per acre is taken as 100.

[2] 7 pounds in 1924 and 1925.

[3] S.P.I. 54478 in the 8-inch and 16-inch tests for 1925–27, an early slender type with small heads; S.P.I. 22329 in 40-inch row tests, 1922–24; C.I. 182–1 in 40-inch rows, 1926–27, and in all row widths, 1928.

The results of these experiments from 1922 to 1928, inclusive, are shown in table 12. The yields of the same varieties in 40-inch rows in the regular variety test are also shown as a check on the merits of the close drills. The yields of Freed in 40-inch rows in 1924 and 1925 were from special plots directly comparable with the close drills. The last column of table 12 is only a fair index rather than an exact

one of the possibilities of each variety and method. It is clear, however, that the 40-inch rows were definitely superior, and it seems that if close-drilled sorghums are to be grown economically for grain production, suitable varieties are yet to be developed. Such a variety must be early and resistant to lodging and drought.

### NURSERY EXPERIMENTS

Sorghum nursery experiments were conducted throughout the entire period 1913–28, with a view to the improvement of the crop. The sorghums were usually grown in single rows from 4 to 8 rods long. Promising lots were advanced to yield tests in larger plots. Three general methods were employed in obtaining material: (1) Introduction of material obtained from foreign countries, principally by the Division of Foreign Plant Introduction, or from outside sources in this country, such as plant breeders, seedsmen, and farmers; (2) selection of seed chosen from apparently superior individual plants observed on the station or elsewhere; (3) by crossing, usually with a definite plan for combining the superior qualities of two or more varieties.

The three methods outlined have been followed largely in the order stated. These sorghums were then sent to stations of the Division of Forage Crops and Diseases for testing, the Hays project receiving mainly those of known or supposed early maturing tendencies. While this method earlier contributed some valuable plants, such as feterita in 1906 and Sudan grass in 1909, it did not develop any new crops of outstanding value from the work at Hays. By the time the Hays project was established, the possibilities appeared greater for the improvement of sorghums by selection among the many varieties already on hand. As long as a good deal of variation exists in a variety the selection method including head-to-row planting is effective in isolating the best types. When a variety is practically uniform, selection usually fails to yield much improvement. The outstanding contribution from the selection method on this project was Early Sumac sorgo, which has been widely distributed since 1922 by the pure-seed department of the Hays station. Many lots grown in the varietal experiments have been improved by the mass selection of heads used to continue the tests.

Since sorghums cross freely among themselves and usually show a marked increase of vigor in the $F_1$ generation, natural hybrids, either of known or unknown parentage, are constantly tempting sorghum growers and amateur breeders. As such hybrids ordinarily break up into a wide range of inferior forms, very little investigation of such types was undertaken at Hays except to determine the value of strains developed or promoted by other agencies. In the more recent years it was concluded that the most effective method of improvement in sorghums is by controlled crosses to combine certain definite qualities, and a start was made by the writer on several projects of this kind.

The work conducted by the various methods will be presented in detail in separate discussions of the different varieties or varietal groups studied.

### SUMAC SORGO GROUP

The standard Sumac sorgo, widely grown throughout the southern Great Plains and the favorite forage sorghum in that section, is too large and too late a variety to mature regularly at Hays, Kans.

Sumac is preferred in the southern part of the sorghum belt not only because of its excellent forage quality and high yields but also because of the uniformity and attractiveness of the seed crop. Its compact heads show much less deterioration from natural crossing with other sorghums than do the loose-panicled varieties such as the Ambers. Black Amber has been widely grown in western Kansas, and Red Amber, considered superior to the Black, was the leading sorgo distributed from the Hays station during the early years of these experiments. Many growers, however, were not satisfied with the forage quality of either of the Amber sorgos and insisted on trying later-maturing and leafier varieties. Other growers were developing local strains of Sumac by continued selection for earlier maturity. The writer began collecting such strains in 1916 and obtained two lots: One was direct from the late H. W. Joy, a farmer living 10 miles northeast of Hays, to which F.C. 02552 was assigned, this number being superseded in 1924 by F.C. 6611. The other strain was obtained from shocks in a field near Hays and was assigned F.C. 02551. Both were placed in the sorghum variety test. The two lots were so similar that F.C. 02551 was soon discarded. In the fall of 1918, 38 head selections were made from the plots of F.C. 02552. These were included in duplicate head-to-row tests in 1919 along with 10 lots from other sources. The 38 were very uniform and the 15 lots showing heaviest forage yields were retained. These 15 were grown in duplicate $\frac{1}{20}$-acre plots in 1920 and were so uniform that no further selection appeared worth while. All were threshed together and furnished the foundation stock for the station's first general distribution of Early Sumac in the spring of 1922.

Early Sumac, F.C. 6611 (fig. 9), soon took the place of Red Amber in the station's pure-seed program and has been found particularly well adapted to the north and west of Hays. With the gain of two weeks or more in earliness, however, there was a corresponding loss in tonnage as compared with standard Sumac. F.C. 6611 did not make full use of the seasons of favorable moisture and late fall frosts at Hays and southward. Some growers in eastern Kansas commended F.C. 6611 for being adapted to the thinner soils; also, as it did not grow so large, it was less difficult to handle than the later varieties.

A Sumac sorgo of heavier foliage and tonnage, maturing not more than 5 days later than F.C. 6611, would be welcomed in many parts of Kansas and would probably supersede F.C. 6611 except in the northwestern section. Numerous commercial lots were tested within the period 1918–28, with a view to finding something midway between standard Sumac and F.C. 6611 from which a suitable strain could be developed. A study of types resulting from a cross of Orange and Sumac, F.C. 6617, was also made. None of the foregoing efforts produced a superior strain of the desired type. Meanwhile, beginning in 1923, a white-seeded Sumac, F.C. 9100, developed by I. N. Farr, of Stockton, Kans., was under investigation. This variety was developed from a cross of Sumac with feterita. The white-seeded character proved fixed, but the heads were rather late in maturing and did not fill satisfactorily, the seeds were small and uncertain in germination, and the forage quality was inferior to Sumac.

In 1924 the writer made crosses of Early Sumac with Dwarf hegari, hoping to develop a more satisfactory white-seeded, smut-resistant

Early Sumac. When the $F_4$ generation was grown in 1928, several early, white-seeded strains had been developed, but none were particularly attractive, and all were susceptible to kernel smut.

### AMBER SORGO GROUP

At the time the forage-crop work was begun at Hays in 1913, Red Amber was the most popular sorgo on the station and was being recommended and distributed to replace the Black Amber more commonly grown. Red Amber matured a few days later than Black Amber, but was leafier, heavier in tonnage, and more uniform. Black Amber, on the other hand, was noted for earliness and seed production, for its certainty of germination, and for drought and insect resistance, but was notably inferior in purity and forage quality.

More than 100 heads of Black and Red Amber, selected at the Akron, Colo., station in 1912, were included in head-to-row tests at Hays in 1913. Selection work was continued the following year with 26 of the Black Ambers and 10 of the Red. The wider variability in the black-seeded lots permitted ready improvement. F.C. 7038 was at once isolated because of its superior forage yield and its resistance to lodging. It is a little later and coarser than the average of the Black Ambers and was carried into the variety tests as a worthy rival of Red Amber, S.P.I. 17548. Later attempts to improve F.C. 7038 by further selection were unproductive. Likewise, numerous selections and commercial lots brought in from other places were inferior to F.C. 7038. This strain was never distributed, however, as the Red Amber already being recommended seemed to fill the same needs. Red Amber selection work throughout 1913–15 was not productive of a strain superior to the check, S.P.I. 17548.

Work was resumed on an extensive scale in 1919 with 128 head selections, mostly from the Hays station general field of S.P.I. 17548. These selections were reduced to 23 in 1920 and later to 15, which were carried in yield tests throughout 1921–23 in comparison with the check, S.P.I. 17548. The best three selections averaged 6 percent above the check in forage yields for the 4 years, 1920–23, but these yield differences were not considered significant. Selection work was then discontinued, Red Amber having lost its popularity because of its susceptibility to head smut and the development of Early Sumac. Attention was given throughout the period 1915–23 to a shorter, coarser-stemmed Red Amber, F.C. 6685, which in the variety tests proved lighter in tonnage but much heavier in seed yield than the relatively tall and slender S.P.I. 17548. This strain was finally discarded also, since forage quality rather than high-seed production was the objective.

### WHITE-SEEDED SORGOS

Among the sorghum introductions there are several, like the White African, that have white seed and others, like Sourless, that have seed which is white tinged with brown on the exposed portions. The brown color in sorgo seed seems to be linked with the presence of a bitter principle resembling tannin. This bitterness has long been accounted the reason for the lower feeding value of sorgo seed as compared with the seeds of kafir, milo, and feterita. It seemed a

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reasonable hypothesis, therefore, that a white-seeded, smut-resistant sorgo would be more valuable than the brown-seeded sorgos like Sumac and Amber. White African requires too long a growing season for Hays, Kans., conditions, and besides, it is susceptible to smut. Sourless matures in central Kansas, but is susceptible to smut and does not have pure white seed.

Crosses between Red Amber and feterita received considerable attention beginning in 1919. In that year the writer received two lots of bulk seed of these crosses from I. N. Farr, Stockton, Kans. and grew one twentieth of an acre of each. The wide range of variations produced and the interesting possibilities of isolating a white-seeded smut-resistant sorgo attracted the attention of John H. Parker, of the Agronomy Department, Kansas State College of Agriculture and Applied Science, and A. F. Swanson, of the Bureau of Plant Industry, who took over the material and made an exhaustive genetic study of it for several years. By 1923 several sweet-stemmed, white-seeded strains had been produced, the most promising being at Hays in the cooperative varietal tests of 1924 under F.C. 9120, 9121, and 9122. Eventually all of the material was discarded, mainly on account of lodging habits inherited from the Red Amber parent. The hybrid strains were more like Red Amber than feterita in vegetative habits, being relatively tall and slender stemmed. A factor in lodging probably was the seed head, which was heavier than that of Red Amber.

During the period from 1922 to 1928 several other selections of Red Amber × feterita were grown. These had been received from I. N. Farr and had already been carried through several generations to a white-seeded sorgo stage. Head rows were continued several years from the more promising lots, but no strains of superior value were found.

Work with the cross, Sourless × Blackhull kafir, though most actively conducted at the Manhattan station, will be included in this discussion because of the positive results of far-reaching value achieved by Mr. Farr through several generations of selection until he had a number of strains carrying a small kafir head on a relatively tall leafy stalk. Thirty-two heads of this material were received from Farr and grown in head-row tests at Hays in 1922. They were a promising group, 68 to 80 inches tall, with the forage quality of Sourless and carrying nonbitter kafir seed, rather light in grain yields, and a bit late maturing, but suggesting rivalry with Sunrise kafir as a dual-purpose crop. Two rows were selected for further study under F.C. 9102 and 9103. Farr also furnished heads of this cross to Parker at Manhattan, Kans., where it immediately appeared to be well adapted. Parker soon developed selections rivaling in forage value and excelling in resistance to lodging the Kansas Orange sorgo, then the leading sorgo at Manhattan. Among six of Parker's selections which he sent to Hays in 1924, one assigned F.C. 9112 appeared especially attractive and was continued in the Hays variety test. Meanwhile, selections continued at Manhattan until one of the larger and later types was decided on for dissemination in 1928 under the name of Atlas sorgo. This selection was recommended primarily for eastern and southern sections of Kansas, but in spite of its relatively late maturity, it is popular in the territory served by the Hays station. Earlier selections were under observation at Manhattan

and Hays in 1928 with a view to perfecting a type better suited to the northwestern section of Kansas, but these selections were not particularly attractive.

### MISCELLANEOUS SORGOS

Several hundred varieties, selections, or commercial lots of sorgos were grown at Hays one or more seasons in single-row tests, and a few of the principal ones were carried in the variety tests of yield comparisons. Only limited breeding efforts were directed toward these miscellaneous sorgos, but an important point in these studies was to become as familiar as possible with the entire range of sorgos being grown in the country, and their trade names. The Orange group was one of the principal ones studied, including not only commercial lots but also crosses with Sumac made by H. N. Vinall, of the Division of Forage Crops and Diseases, and selections of Kansas Orange developed by Parker at Manhattan. The general run of this Orange

FIGURE 13.—The taller sorghums produce heavy yields of forage, but are subject to lodging badly in years of heavy rainfall. This is a factor to be considered in evaluating sorghum varieties.

and other material was rather late and tall for the Hays section (fig. 13). Many sorgos of good forage quality were observed in these plantings, but it seemed impossible to find any superior to the best standard types of Orange, Sumac, and Honey.

In 1926 the tests included 145 lots of sorgo collected under Vinall's direction in many of the sorghum-growing States. These sorgos carried a confusing list of local names. Some of the lots tentatively identified as Orange, for example, were received under such names as Honeycomb, Honey Drip, Silver Drip, Sugar Cane, Silvertop, Beckdale Cane, Orangetop, Klondike Cane, California Cane, Georgia Poorland, etc. Practically all of the lots were readily identified as belonging to a few standard varieties such as Orange, Colman, Planter, Sourless, Red Amber, Black Amber, and Honey.

KAFIR GROUP

*Pink kafir.*—Some attention was given to the improvement of Pink kafir by selection. Pink kafir, C. I. 432, had been developed at the Hays station and grown for distribution under the name Whitehull White kafir prior to the establishment of the forage-crops project. About 1915 it became known as Pink kafir, because the seeds were tinted with pink. This variety has continued very popular in Kansas wherever a kafir is needed that is somewhat earlier and more drought resistant than standard Blackhull kafir. Farmers seem to grow it fully as much for forage as for grain production. In 1919, 88 head selections and commercial lots of Pink kafir were assembled from various sources and grown in duplicate 4-rod rows. Two outstanding selections were developed. F.C. 9089 was a week or more earlier than C.I. 432, but pithy stemmed and deficient in leafiness. F.C. 9091 selected from a commercial lot of seed handled by the D. O. Coe Seed Co., Topeka, Kans., was 100 percent juicy stemmed, whereas only

FIGURE 14.—Pink kafir, a dependable grain and forage sorghum. Uniformity was attained by continued selection.

22 percent of the stalks in the check plot of C.I. 432 were juicy. Otherwise, the merits of F.C. 9091 and C.I. 432 were apparently equal, and the substitution of F.C. 9091 for general distribution was considered (fig. 14).

*Dawn kafir.*—C.I. 340, a dwarf blackhull type developed at the Amarillo, Tex., cereal field station about 1908, was grown in the Hays variety tests regularly and distributed by the Hays station for several years, but showed too much variation to be classed as a pure strain, and indicated considerable opportunity for improvement by selection. Numerous head selections were made in 1918 and seeded in head rows in 1919. A. F. Swanson then took over this material and after several years developed a more uniform type, C.I. 904, slightly leafier and taller than C.I. 340. The selection was grown in the variety tests from 1925 on, and superseded C.I. 340 in the station's seed trade.

*Western Blackhull kafir.*—F.C. 9098 was developed from early local selections of Blackhull by P. E. Crabtree, near Scott City, Kans.

Beginning in 1921, it was included in the varietal tests regularly and found to be a very uniform attractive kafir, 10 days or so earlier than standard Blackhull kafir, and therefore much better adapted to western Kansas conditions (fig. 15). It proved a close rival of Dawn kafir throughout the tests, and finally in the spring of 1931 it was seeded in place of Dawn on the station farm for commercial distribution. Early local strains of Blackhull kafir have long been grown to the southwest of Hays, and Western Blackhull should appeal to growers who desire a pure uniform strain. Blackhull kafir, Texas No. 9195 (C.I. 865), developed and distributed from the Lubbock, Tex., station, was grown at Hays in 1927 and 1928 in the sorghum-variety tests and was

FIGURE 15.—Western Blackhull kafir, one of the new strains, showing its uniformity and productiveness.

found to be practically identical with the Western Blackhull kafir, F.C. 9098.

The name kafir has become rather loosely used, so that it is now attached to sorghums that are not true kafirs in the original sense. Such varieties are "Wonder kafir", described under the heading Feterita; Yellow kafir, C.I. 902, a milo-kafir hybrid developed by A. F. Swanson; Progressive kafir, F.C. 02249, an H. Willis Smith hybrid; and Schrock kafir, F.C. 1481, a sorgo-kafir hybrid designated in this bulletin merely as Schrock or Schrock sorghum.

### FETERITA GROUP

On account of its newness, attractive white seeds, and unusual drought resistance, feterita became popular during the period 1913 to 1915 but has since declined to minor importance in Kansas. This decline was due to the soft seeds germinating poorly under unfavorable weather conditions, to poor forage quality, and to the fact that the improvement of the crop did not keep pace with that of other sorghums. The poor germination is so serious a difficulty with the

average farmer as to obscure the advantages of feterita in other respects.

Under the careful cultural methods used in the variety tests at Hays, obtaining feterita stands was not unusually difficult, and the tables presented show that the grain yields of several selections of feterita ranked with the best kafirs, Dawn and Pink, at about 20 percent above the average yield of the 10 varieties used as a check.

The experiments with feterita included the following introductions and selections: (1) Varietal tests of F.C. 811, S.P.I. 19517, and S.P.I. 22329, developed by H. N. Vinall and others at the Chillicothe, Tex., substation, for greater uniformity and a minimum of branching and stooling; Spur feterita, F.C. 6601, developed at the Spur, Tex., substation by R. E. Dickson; Dwarf feterita, F.C. 9076, selected by H. N. Vinall at San Antonio, Tex. (fig. 16); earlier selections superseded in

FIGURE 16.—A dwarf strain of feterita deve'oped by the Division of Forage Crops and Diseases. This strain failed to achieve practical importance because of the low germination of the soft seed.

1924 by C.I. 182–1, developed by A. F. Swanson on the Hays cereal crops project; (2) numerous Egyptian introductions tested from 1922 to 1927; and (3) testing of hybrids developed by several plant breeders, 1922–28.

The varietal-test tables show yields for the feteritas under class 1 and for some of the hybrids. C.I. 182–1 was used for distribution by the Hays station for a number of years but is too tall to meet the modern trend toward grain sorghums suitable for handling with the header and combine. Spur feterita is an improvement as to foliage but does not have the earliness and drought resistance which constitute the chief reasons for growing feterita in the Hays section. Dwarf feterita, F.C. 9076 and 8628, were pleasing from the standpoint of reduced height but had the softest and poorest germinating seed of all the feterita group.

Egyptian introductions of feterita were tested in single rows in 1922 under the following S.P.I. numbers: 54478, 54480, 54482, 54483, 55106, 55116, 55127, 55154, 55155, 55157, 55159, and 55163.

Other Egyptian feteritas received at Hays in 1926 after preliminary trials at Shafter, Calif., included S.P.I. 61448, 61450, 61458-A, and 61458-B. In 1927 the testing of the foregoing lots had narrowed to three—S.P.I. 54478, 61450, and 61458-B. All were relatively small-headed, slender types that might show up well in a dry year or perhaps be suited to growing in close drills. The 1927 season was wet, and these three feteritas grew 6 feet tall. They also tillered, branched, and lodged more than C.I. 182–1.

The results with Red Amber and Sumac crosses on feterita have been discussed. Otherwise the most extensive work on feterita crosses was done by Vinall and others at the Chillicothe, Tex., substation, and some of their crosses were sent to Hays for further test. Most notable of these creations were Chiltex, F.C., 8917, and Premo, F.C. 8929, crosses between feterita and kafir, both of which were

FIGURE 17.—Freed sorghum, an early variety that often matures grain in a dry year when late varieties fail.

grown for several years in the Hays variety tests. Chiltex was uniform and productive and showed some gain over feterita in germination. It was less drought-resistant than feterita and lacked attractiveness either for forage or grain in competition with the best kafirs. Premo was later and less well adapted, and many heads were poorly exserted from the boot. Milo × feterita, F.C. 8926, appeared more drought-resistant and productive than feterita, but was not a well-fixed type. Other less advanced hybrids with feterita ancestry were grown in head rows in 1924 and later under F.C. 6612, 6618, 6619, 6620, 6621, 6622, 6623, 6627–1, and 6627–4.

Three feterita hybrids developed by amateur plant breeders are of sufficient importance to discuss here: (1) F.C. 9096, Red kafir × milo × feterita, by H. Willis Smith, obtained at his farm near Kismet, Kans., in September 1921, a medium dwarf, competing with Dwarf feterita, F.C. 9076, but was discarded after a trial of 3 years. (2) "Wonder kafir", C.I. 872, developed by C. A. Bowers, Wallace, Kans., from a

chance hybrid of feterita and kafir. This was an attractive type, medium dwarf and, under favorable conditions, prolific like Dwarf hegari. However, the varietal tests (1925–28) revealed three severe defects—weak germination, lodging, and susceptibility to kernel smut. (3) Feterita × kafir, C.I. 969, a true dwarf feterita, developed by I. N. Farr. It was included in the variety tests of 1925 to 1928. If developed further it might prove sufficiently valuable for local distribution.

### FREED SORGHUM GROUP

Freed, a very early, white-seeded sorghum developed by J. K. Freed, Scott City, Kans., produced a light tonnage, with stalks medium fine, juicy, and slightly sweet, thus making Freed a dual-purpose forage and grain crop for extreme western Kansas and tributary areas in Colorado and Nebraska. It was grown throughout the Hays variety tests, first under S.P.I. 29166. This number, after a series of head-to-row plantings in 1913–14, was superseded by F.C. 9033, which was apparently more uniform, wind resistant, and productive of grain (fig. 17). Later, a true dwarf, Freed, C.I. 971, was developed through selection by A. F. Swanson and included in the variety tests. This selection was an improvement from the grain standpoint because of convenience in handling and resistance to lodging.

P. E. Crabtree crossed Freed with Pink kafir, hoping to combine some of the earliness and dependability of the Freed with the superior tonnage and grain-yielding habit of the kafir. In 1918 a plot of this cross in the $F_2$ generation showed many segregates. The writer was permitted to make numerous selections, which were carried forward in head-to-row tests for several years to fix desirable types. Finally these narrowed to Weskan and Modoc, which were included in the variety test. Weskan, an exceptional grain yielder under favorable conditions but too much subject to lodging, was near the Pink kafir type in forage habits, but with a more lax panicle. Modoc yielded less but was medium tall, stood up satisfactorily, had a small but attractive head that was fairly compact, and produced excellent grain yields. It appeared suitable to replace Freed as a dual-purpose crop.

### KAOLIANG GROUP

*Dwarf Brown kaoliang.*—S.P.I. 38202, grown in 1922, was 5 to 6 feet tall and of no forage value. Kaoliangs introduced from Echo, Manchuria, were grown in 1924 under S.P.I. 57284 to 57295, inclusive. F.C. 11557 and 11571 were also in the collection. With three exceptions, all were true Brown kaoliangs 5 to 6 feet tall, maturing grain and shedding their leaves early, hence of no possible forage value. Nos. 11557 and 57286 differed in showing more of a broomcorn-head type. No. 57293 differed in having loose heads of the Amber type.

Five more kaoliang introductions from Peiping, China, were grown in 1925—S.P.I. 62608, 62609, 62428, and 63437, Brown kaoliangs, and S.P.I. 62610, White kaoliang. None of these was attractive. A new collection of 30 Manchurian kaoliangs were grown in 1926—S.P.I. 66368 to 66393, 63715, 63923, 64368, and 66741, and these were principally Brown kaoliangs of standard height, some partly white seeded. The only one of interest was S.P.I. 66384, a dwarf Brown kaoliang 48 inches tall, 1 to 2 feet shorter than other kaoliangs. In head type it was identical with C.I. 171, but a definite improvement. S.P.I. 66384 was, however, a relatively light grain yielder compared

with other grain sorghums and of no possible forage value. Crosses with Dawn kafir, Dwarf Freed, and White Durra were made at the suggestion of H. N. Vinall in 1927, and the $F_1$ generation was grown in 1928.

#### MISCELLANEOUS SORGHUMS

Several other sorghums not yet discussed are of sufficient interest to mention here. Schrock sorghum, F.C. 1481, originated and distributed by Roy Schrock, Enid, Okla., as Kafirine, later known as Schrock kafir, Kafir-sorghum, and finally as Sagrain by Mississippi growers, was grown throughout the sorghum-variety test because of its excellent forage habits and also because of the constant interest of the public in its performance. Its vegetative habit is that of a very leafy kafir, but the grain is bitter. Although it yields less forage it produces more in proportion to its height than the taller sorgos. Schrock was considered a desirable subject for crossing with a grain sorghum for the purpose of developing a plant combining its forage habits and a nonbitter grain. The writer crossed Schrock with Dwarf hegari in 1927 and grew the $F_1$ generation in 1928.

Fargo milo, C. I. 809, also known as Straight-neck milo and Manko maize, is a tall, late, rather leafy grain sorghum. Apparently developed locally at Fargo, Okla., it has spread rapidly north and west into southwestern Kansas. It was included for three seasons in the Hays variety tests and was considered very inferior, something like a very late standard milo, except the heads were looser and only partly inclined. Under the name Manko maize, it was extravagantly promoted in 1928, and the seed sold at a fancy price.

Algeria, a very late type of sorghum identified as Bishop kafir, was grown at Hays in 1928, on account of its promotion from the same source as Manko maize.

## GRASS SORGHUMS

### SUDAN GRASS

Among the numerous grass sorghums found growing naturally in Africa, Sudan grass is the only one which has proved useful in the United States as a cultivated crop. It is particularly suited to the semiarid conditions in the Great Plains and has been given a thorough test at the Fort Hays station. Naturally other grass sorghums when introduced were compared in preliminary tests with Sudan grass, and as they proved less valuable they were discarded.

#### DATE OF SEEDING FOR HAY PRODUCTION

Close-drilled seedings of Sudan grass for hay production were made at the rate of 20 pounds per acre at 15-day intervals from April 15 to August 1 for 1913–18. Land for the experiment was measured and prepared previous to the first seeding. Additional tillage was given the unseeded portion to kill successive crops of weeds and to get the land into as good tilth as possible for each seeding.

The April 15 seedings suffered badly from cold weather. Poor stands grew so slowly that they were partly or wholly smothered by pigweeds. The May 1 and May 15 seedings were also subject to weed competition in certain seasons, to an extent indicated by percentages of stand in table 13, but these seedings, favored by warmer weather, soon grew vigorously. In seedings made after May 15 weeds were not an important factor, for successive crops of them had been

TABLE 13.—*Results from seeding Sudan grass in close drills at different dates for hay production, 1913–18*

| Year and date of seeding | Stand | First cutting | | | Second cutting | | | Total yield per acre |
|---|---|---|---|---|---|---|---|---|
| | | Date | Time after seeding | Yield per acre | Date | Time after first cutting | Yield per acre | |
| 1913: | *Percent* | | *Days* | *Tons* | | *Days* | *Tons* | *Tons* |
| Apr. 16 | 10 | July 9 | 84 | 0.03 | [1] | | | 0.03 |
| May 1 | 20 | ---do | 69 | .12 | | | | .12 |
| May 14 | 100 | ---do | 56 | 1.08 | | | | 1.08 |
| May 30 | 100 | Aug. 13 | 75 | .26 | | | | .26 |
| June 16 | 100 | ---do | 58 | .10 | | | | .10 |
| July 2 | | | | | | | | |
| July 15 | | | [2] | | | | | |
| Aug. 1 | | | [2] | | | | | |
| 1914: | | | | | | | | |
| Apr. 14 | 10 | [3] | | | | | | |
| May 6 | 100 | July 20 | 75 | 2.17 | Sept. 15 | 57 | 0.25 | 2.42 |
| May 21 | 100 | July 28 | 68 | 2.30 | ---do | 49 | .31 | 2.61 |
| June 4 | 100 | Aug. 5 | 62 | 2.18 | ---do | 41 | .26 | 2.44 |
| June 19 | 100 | Aug. 19 | 61 | 1.65 | ---do | 27 | .47 | 2.12 |
| July 3 | 100 | Sept. 15 | 74 | 1.66 | None | | | 1.66 |
| July 16 | 100 | ---do | 61 | 1.68 | ---do | | | 1.68 |
| Aug. 1 | [4] | | | | | | | .45 |
| 1915: | | | | | | | | |
| Apr. 15 | | [3] | | | | | | |
| May 5 | 60 | Aug. 3 | 90 | 1.81 | Sept. 28 | 56 | 2.50 | 4.31 |
| May 14 | 60 | Aug. 14 | 92 | 2.46 | Oct. 20 | 67 | 1.15 | 3.61 |
| June 1 | 90 | Aug. 18 | 78 | 2.42 | ---do | 63 | 1.12 | 3.54 |
| June 15 | 100 | Aug. 31 | 77 | 3.79 | ---do | 50 | .80 | 4.59 |
| July 6 | 100 | Sept. 11 | 67 | 3.25 | None | | | 3.25 |
| July 17 | 100 | Sept. 28 | 73 | 2.46 | ---do | | | 2.46 |
| Aug. 4 | 100 | Oct. 20 | 77 | 1.25 | ---do | | | 1.25 |
| 1916: | | | | | | | | |
| Apr. 19 | 50 | July 4 | 76 | .46 | Sept. 6 | 64 | .77 | 1.23 |
| May 1 | 40 | ---do | 64 | .34 | ---do | 64 | .67 | 1.01 |
| May 15 | 40 | ---do | 50 | .24 | ---do | 64 | .51 | .75 |
| May 31 | 95 | July 28 | 58 | .99 | Oct. 1 | 65 | .20 | 1.19 |
| June 17 | 80 | Aug. 1 | 45 | .52 | ---do | 61 | .34 | .86 |
| July 1 | 100 | Oct. 1 | 92 | 1.01 | None | | | 1.01 |
| July 15 | 50 | ---do | 78 | .93 | ---do | | | .93 |
| Aug. 1 | 50 | ---do | 61 | .10 | ---do | | | .10 |
| 1917: | | | | | | | | |
| Apr. 20 | 20 | Aug. 18 | 120 | .18 | ---do | | | .18 |
| May 1 | 40 | ---do | 109 | .33 | ---do | | | .33 |
| May 16 | 100 | Sept. 4 | 111 | 1.75 | ---do | | | 1.75 |
| May 31 | 100 | ---do | 96 | 2.11 | ---do | | | 2.11 |
| June 15 | 25 | ---do | 81 | 2.15 | ---do | | | 2.15 |
| June 29 | 100 | ---do | 67 | 2.63 | ---do | | | 2.63 |
| July 12 | 95 | Sept. 11 | 61 | 1.64 | ---do | | | 1.64 |
| Aug. 1 | 90 | Oct. 13 | 73 | 1.17 | ---do | | | 1.17 |
| 1918: | | | | | | | | |
| Apr. 18 | 60 | Aug. 1 | 105 | .76 | ---do | | | .75 |
| May 2 | 75 | ---do | 91 | .85 | ---do | | | .85 |
| May 15 | 75 | ---do | 78 | 1.21 | ---do | | | 1.21 |
| June 1 | 100 | ---do | 61 | 1.49 | ---do | | | 1.49 |
| June 15 | 100 | Aug. 14 | 60 | 1.42 | ---do | | | 1.42 |
| July 1 | 100 | Aug. 23 | 53 | 1.13 | ---do | | | 1.13 |
| July 15 | 100 | Sept. 22 | 69 | 1.06 | ---do | | | 1.06 |
| July 31 | 100 | ---do | 53 | .56 | ---do | | | .56 |
| Average [5], 1913–18: | | | | | | | | |
| Apr. 17 | 25 | July 23 | 96 | .24 | | 64 | .77 | .37 |
| May 3 | 56 | July 25 | 83 | .94 | | 59 | 1.14 | 1.51 |
| May 16 | 79 | July 31 | 76 | 1.51 | | 60 | .66 | 1.84 |
| June 1 | 98 | Aug. 12 | 72 | 1.58 | | 56 | .53 | 1.84 |
| June 16 | 84 | Aug. 19 | 64 | 1.61 | | 46 | .54 | 1.87 |
| July 2 | 83 | Sept. 11 | 71 | 1.61 | | | | 1.61 |
| July 15 | 74 | Sept. 21 | 68 | 1.30 | | | | 1.30 |
| Aug. 1 | 68 | Oct. 6 | 66 | .59 | | | | .59 |

[1] Extreme drought prevented second growth on all plots.
[2] Last actual seeding was made July 2, but increasing severity of drought prevented the later seedings from germinating.
[3] Smothered by weeds.
[4] Seeding omitted; yield interpolated.
[5] Averages include only those years in which a cutting was actually made; 1 year in the case of the second cutting from the earliest seeding; 4 years from second cuttings for the next 4 dates of seeding. This accounts for the sum of first and second cutting averages being greater than the amounts given for the respective dates in the total-yields column. This apparent discrepancy could be avoided if all second-cutting yields were averaged strictly on a 6-year basis, but the average number of days since first cutting should not be so handled.

killed, and the grass had vigor enough to develop steadily through cold wet periods. From July 1, 1913, on, the surface soil was too dry for seed to germinate, and there was some irregularity of stands from this cause in the two latest seedings of 1916 and 1917.

The first cutting of hay was generally made from the first head to the full-bloom stage. Seedings as late as July 15 were generally able to produce one such cutting. The August 1 seedings developed poorly. Second cuttings were obtained in three seasons from the May 1 to June 15 seedings, but only in the very wet season (1915) were these cuttings of much value. Because of shortage of soil moisture, the second growth was generally slow starting and became stunted when 6 to 30 inches tall.

The earlier the seeding the greater the tendency for the Sudan grass to exhaust the soil moisture and suffer a noticeable loss in the quality of the first cutting. Later seedings derived much advantage from a reserve of moisture usually accumulated during their longer soil-preparation period, but the danger of the immediate surface soil becoming too dry at seeding time increased after June 15.

No definite optimum date of seeding was shown from these experiments. The optimum 10-day period for each season was noted as follows: 1913, May 10 to 20; 1914, May 20 to 30; 1915, June 10 to 20; 1916, May 29 to June 8; 1917, June 20 to 30; 1918, June 1 to 10. It was concluded that there was nothing to be gained by seeding before May 15, but that seeding might well be done as soon after this date as warm weather and a good seed bed were available. It was better to wait several weeks if necessary rather than seed Sudan grass under unfavorable soil or climatic conditions. As with early-maturing sorghums, this crop has a wide seeding range, and a fair crop is possible if 80 to 90 days remain before the normal date of the first killing frost. Cold nights usually prevent normal development of the grass at Hays, Kans., after September 25.

It is often desirable to seed relatively early in order to get the hay or pasture as soon as possible, but it may be noted in table 14 that prior to June 1, seeding 2 weeks earlier permitted cutting only 1 week earlier. It may be desirable, especially for pasture, to spread the seeding over several dates, in order to have new areas in full growth in August and September after the earlier seedings have exhausted their moisture supply. The poorer the physical condition of the soil, as, for example, after sorghums or Sudan grass, the later a following crop of Sudan grass should be sown, for the land needs more time to acquire moisture and good tilth.

### RATE AND METHOD OF SEEDING FOR HAY PRODUCTION

Experiments were begun in 1913 with seeding Sudan grass in close drills at four rates, 35, 25, 20, and 15 pounds per acre; seeding in alternate drill rows 16 inches apart at 10 pounds per acre; also in 24-inch and 40-inch cultivated rows at 7 and 4 pounds per acre, respectively. All seedings were made with a grain drill equipped with press wheels. The land was prepared intensively, and the seedings made at as nearly an optimum date as possible. The average date was June 4, but varied between May 14 and June 25. Duplicate $\frac{1}{20}$-acre plots were used, except that in five seasons the replications were put in about 2 weeks apart. The scope of this experiment was gradually reduced after 1918, as results became fully established.

The annual yields from this experiment are shown in table 14, including average yields for the different periods that each method was tested. No consistent differences in yield were obtained among the noncultivated seedings. There is more assurance of a good stand and freedom from weeds if every drill row is sown than if only alternate ones are seeded, but the expense for seed is greater. The 24-inch rows led by 5 to 10 percent, as compared with either the 20-pound rate in close drills or the 40-inch cultivated rows. This difference agrees very closely with results from all sections of the United States.[7]

TABLE 14.—*Results from seeding Sudan grass for hay production at different rates and in different widths of rows, 1913–28*

| Year | Acre yields for rates and row widths shown | | | | | | |
|---|---|---|---|---|---|---|---|
| | Close-drilled seedings | | | | | Cultivated rows | |
| | 35 pounds | 25 pounds | 20 pounds | 15 pounds | 10 pounds [1] | 7 pounds in 24-inch rows | 4 pounds in 40-inch rows |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* |
| 1913 | 0.71 | 0.60 | 0.49 | 0.39 | [2] 0.60 | 0.76 | 0.64 |
| 1914 | 4.44 | 3.85 | 3.80 | 4.16 | 4.18 | 4.17 | 4.32 |
| 1915 | 4.12 | 4.45 | 4.26 | 4.22 | 4.21 | 4.39 | 3.77 |
| 1916 | 1.83 | 1.76 | 2.07 | 2.04 | 1.93 | 2.46 | 2.59 |
| 1917 | 1.83 | 1.92 | 2.02 | 2.23 | 2.00 | 2.34 | 1.65 |
| 1918 | 1.76 | 1.79 | 1.96 | 1.93 | 1.93 | 1.91 | 1.70 |
| 1919 | | | 2.20 | | 2.80 | 3.17 | 3.20 |
| 1920 | | | 3.14 | | 3.25 | 3.39 | 3.29 |
| 1921 | | | 2.81 | | 2.64 | 2.47 | 2.77 |
| 1922 | | | 3.39 | | 3.07 | 2.98 | 2.71 |
| 1923 | | | 1.70 | | 1.86 | 2.21 | 2.26 |
| Average: | | | | | | | |
| 1913–18 | 2.45 | 2.40 | 2.43 | 2.50 | 2.48 | 2.67 | 2.45 |
| 1913–23 | | | 2.53 | | 2.59 | 2.75 | 2.63 |

[1] 6-inch drills were used in 1913 and 1914; 16-inch drills other years.
[2] Interpolated.

In the earlier years of Sudan-grass culture when seed was unduly expensive it appeared advisable to economize on seed and to regard forage merely as a side line to the production of seed. In such a case the use of cultivated rows may have been justified. But now with seed available at reasonable prices it seems preferable to use from 15 to 25 pounds per acre in close drills and to save the expense of cultivation. Yields by separate cuttings have been studied, showing that close drills at 20 pounds per acre averaged for 8 years a yield of 2.16 tons at the first cutting and only 0.76 at the second. The 24-inch rows yielded 2.03 tons the first cutting and 1.12 for the second; the 40-inch rows 1.86 at the first and 1.26 at the second. For the three methods the percentages of total yield in the first cutting were as follows: Close drills 74, 24-inch rows 64, and 40-inch rows 60 (fig. 18). A close-drilled stand that occupies the land fully at the outset seems to exhaust most of the available moisture by the time of the first cutting. The cultivated rows, requiring longer for their roots to occupy all the space, do not keep up with the close drills at first in volume of growth and seem to have enough available moisture left after the first cutting to start a vigorous new growth.

If circumstances are not entirely favorable for seeding, as in using seed of less than 90 percent germination or in seeding on poorly pre-

[7] VINALL, H. N., and GETTY, R. E. SUDAN GRASS AND RELATED PLANTS. U.S. Dept. Agr. Bull. 981, 68 pp., illus. 1921.

pared land, the rate should be increased. The use of press wheels on a drill appears important in getting uniform stands. The seed should have a firm but shallow covering about half as deep as that of wheat. The grain drills used in these tests sowed about 20 pounds of Sudan grass per acre when set at the 2-peck rate for wheat.

### MIXTURES WITH ANNUAL LEGUMES FOR HAY PRODUCTION

Mixtures of Sudan grass with cowpeas and also with soybeans were tried in close-drilled seedings for hay production at Hays in 1914 and 1915. Results were entirely negative, for the Sudan grass rapidly outgrew the legumes and smothered them. The Sudan grass and legumes were drilled at the same time in alternate drill rows in the ratio of 4 pounds of Sudan grass to 40 of legume seed; also in the ratio of 5 and 50 pounds per acre. The number of legume plants per square foot in the early stands varied from 0.5 up to 5.9. That of Sudan grass was always greater, ranging from 0.9 up to 12.2 plants

FIGURE 18.—Sudan grass. In regions of low rainfall this crop is often more productive of hay and seed when grown in rows and cultivated.

per square foot. Apparently the legumes are unable to survive in close-drilled Sudan grass under dry-land conditions regardless of the seeding ratio. The purpose of this experiment, namely, to secure a forage of higher protein content than Sudan grass alone, can be attained in considerable degree by cutting Sudan grass itself at an earlier stage of growth.

### STAGES OF CUTTING FOR HAY PRODUCTION

Experiments relative to the stage of cutting Sudan grass for hay were conducted for the 5 years 1915–19. Seedings were made in close drills at 20 pounds per acre at an average date of June 3. Duplicate $\frac{1}{20}$-acre plots were mowed at each of four stages: (1) Just before heading; (2) at the first head; (3) at full head; and (4) with the seed in the milk stage. Any second growth that developed was mowed at about the date of the first killing frost or shortly afterward. The

TABLE 15.—*Results obtained from cutting Sudan grass for hay at different stages of maturity, 1915–19*

| Year | Plot nos. | Cutting | Stage of maturity | Height | Date cut | Period after seeding or cutting | Average weight per acre air-dry hay | Composition (water-free material) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Ash | Ether extract | Protein | Crude fiber | Nitrogen-free extract |
| | | | | *In.* | | *Days* | *Tons* | *Pct.* | *Pct.* | *Pct.* | *Pct.* | *Pct.* |
| 1915 | 1 and 5 | First | Before heading | 40 | Aug. 3 | 50 | 0.90 | 12.92 | 1.66 | 15.84 | 30.98 | 38.60 |
| | | Second | do | 42 | Sept. 11 | 39 | 1.72 | 10.72 | 1.23 | 14.82 | 32.72 | 40.51 |
| | | Total | | | | | 2.62 | | | | | |
| | 2 and 6 | First | First head | 70 | Aug. 18 | 65 | 2.38 | 11.99 | 1.15 | 11.54 | 37.42 | 37.90 |
| | | Second | Very young, frosted | 24 | Oct. 20 | [1] 48 | 1.16 | 10.12 | 1.15 | 15.54 | 29.81 | 43.38 |
| | | Total | | | | | 3.54 | | | | | |
| | 3 and 7 | First | Full head | 78 | Aug. 31 | 78 | 3.41 | 8.98 | 1.49 | 10.16 | 35.27 | 44.10 |
| | | Second | Very young, frosted | 18 | Oct. 20 | [1] 35 | .67 | 10.56 | 1.10 | 17.21 | 29.06 | 42.07 |
| | | Total | | | | | 4.08 | | | | | |
| | 4 and 8 | First | Seed in milk | 84 | Sept. 28 | 106 | 3.67 | 8.86 | 1.21 | 7.67 | 37.41 | 44.85 |
| 1916 | 1 and 5 | do | Before heading | 24 | July 15 | 45 | 1.10 | 10.28 | 2.39 | 13.21 | 24.85 | 49.27 |
| | | Second | do | 24 | Sept. 6 | 53 | .75 | 9.92 | 2.51 | 13.90 | 23.94 | 49.73 |
| | | Total | | | | | 1.85 | | | | | |
| | 2 and 6 | First | First head | 34 | July 26 | 56 | 1.24 | 9.57 | 1.96 | 10.42 | 24.57 | 53.48 |
| | | Second | Very young, frosted | 18 | Oct. 1 | 67 | .48 | 9.81 | 1.79 | 11.22 | 22.37 | 54.81 |
| | | Total | | | | | 1.72 | | | | | |
| | 3 and 7 | First | Full head | 36 | Aug. 11 | 72 | 1.15 | 9.96 | 1.45 | 9.31 | 25.70 | 53.58 |
| | | Second | Very young, frosted | 12 | Oct. 1 | 51 | .19 | 14.14 | 1.76 | 11.95 | 21.20 | 50.95 |
| | | Total | | | | | 1.34 | | | | | |
| | 4 and 8 | First | Seed in milk | 36 | Sept. 6 | 98 | 1.59 | 9.35 | 1.60 | 8.67 | 27.76 | 52.62 |
| 1917 | 1 and 5 | do | Before heading | 34 | Aug. 18 | 86 | .61 | 11.77 | 1.70 | 16.86 | 29.59 | 40.08 |
| | | Second | do | 28 | Sept. 26 | 39 | 1.21 | 10.29 | 2.12 | 13.36 | 26.51 | 47.72 |
| | | Total | | | | | 1.82 | | | | | |
| | 2 and 6 | First | First head | 40 | Aug. 28 | 96 | 1.41 | 10.96 | 1.58 | 14.01 | 26.45 | 47.00 |
| | | Second | Very young, frosted | 15 | Oct. 13 | 46 | .57 | 9.20 | 1.82 | 11.98 | 25.24 | 51.76 |
| | | Total | | | | | 1.98 | | | | | |
| | 3 and 7 | First | Full head | 41 | Sept. 11 | 110 | 1.40 | 10.04 | 1.48 | 11.95 | 30.55 | 45.98 |
| | 4 and 8 | do | Seed in milk | 42 | Sept. 26 | 125 | 2.22 | 7.98 | 1.70 | 9.15 | 29.68 | 51.49 |
| 1918 | 1 and 5 | do | Before heading | 42 | July 27 | 51 | 1.03 | 11.67 | 2.21 | 14.87 | 28.34 | 42.91 |
| | 2 and 6 | do | First head | 48 | Aug. 1 | 56 | 1.71 | 10.53 | 2.40 | 14.19 | 28.61 | 44.27 |
| | 3 and 7 | do | Full head | 50 | Aug. 14 | 69 | 1.75 | 10.34 | 2.05 | 10.92 | 30.42 | 46.27 |
| | 4 and 8 | do | Seed in milk | 50 | Aug. 23 | 78 | 1.78 | 9.32 | 1.80 | 9.81 | 30.64 | 48.43 |
| 1919 | 1 and 5 | do | Before heading | 42 | July 21 | 45 | .99 | 9.68 | 1.77 | 9.31 | 29.48 | 49.76 |
| | | Second | First head [2] | 30 | Sept. 27 | 68 | 1.00 | 9.11 | 1.41 | 10.95 | 31.24 | 47.29 |
| | | Total | | | | | 1.99 | | | | | |
| | 2 and 6 | First | First head | 46 | July 26 | 50 | 1.34 | 9.18 | 1.46 | 6.71 | 31.47 | 51.18 |
| | | Second | do [2] | 30 | Sept. 27 | 63 | .88 | 9.11 | 1.41 | 10.95 | 31.24 | 47.29 |
| | | Total | | | | | 2.22 | | | | | |
| | 3 and 7 | First | Full head | 50 | Aug. 2 | 57 | 1.43 | 8.33 | 1.44 | 5.30 | 31.48 | 53.45 |
| | | Second | First head [2] | 30 | Sept. 27 | 56 | .77 | 9.11 | 1.41 | 10.95 | 31.24 | 47.29 |
| | | Total | | | | | 2.20 | | | | | |
| | 4 and 8 | First | Seed in milk | 50 | Aug. 18 | 73 | 2.14 | 8.12 | 1.51 | 5.60 | 32.22 | 52.55 |

[1] Days to killing frost, Oct. 5.

[2] Same sample used for analyses of these three cuttings.

yield and composition of the hay from each cutting was determined, the analytical work being done by the then Bureau of Chemistry, United States Department of Agriculture. The data obtained are shown in detail in table 15.

Marked increase in yields generally resulted from letting the Sudan grass stand an additional 10 days, the average interval from the just-before-heading to the first-head stages. The dry-matter content increased greatly, even though the outward appearance of the crop showed but little change. The percentage of protein was highest in the first stage, but the largest amount per acre for the season was obtained from the second stage. After the first-head stage, the chief increase is in the carbohydrates. The hay becomes rather stemmy and woody at the seed stage.

Some growers advocate the cutting of Sudan-grass hay whenever it is as tall as the mower wheels (about 3 feet) because of convenience in curing and handling the fine quality of hay, and the higher annual tonnage supposed to result from more numerous cuttings. The experimental data here presented indicate that the high-protein hay from such an early cutting is obtained at a considerable reduction in annual tonnage. In a season like 1916, when the growth was checked by drought at about the first stage of cutting and when grasshoppers were attacking the leaves, the earliest stage was decidedly the best. In the wet season of 1915, when conditions at the first stage were ideal for continued growth, the yield more than doubled during the 15-day interval from August 3 to 18, between the first and second stages. It continued to increase from the second to the third stages, adding more than a ton per acre during the period August 18 to 31. The hay at the full-head stage, in 1915 and other seasons of favorable growth, appeared to be of good quality and not so difficult to handle as to offset the higher tonnage.

The conclusions reached were that (1) Sudan grass should usually be cut for hay at the first-head to the full-head stage; (2) earlier cutting may be justified when the crop is being checked in growth or when high-protein hay is sought rather than maximum tonnage and food nutrients; (3) the crop may be cut satisfactorily over a wide range of time, even to the seed stage, but it becomes woody after the seed begins to form.

### SUDAN GRASS FOLLOWING ALFALFA

Sudan grass has been widely used in Kansas for seeding in the irregular areas around the edges of alfalfa fields where stands of the latter crop have been lost because of grasshoppers or other causes. It has also been grown successfully on numerous fields where the entire alfalfa stand has declined and has been plowed up and where new stands of alfalfa have been hard to get. Plots of Sudan grass were grown at Hays in 1927 and 1928 on a bottom-land field where a 20-year-old stand of alfalfa had become too thin to leave. Table 16 compares the yields on alfalfa land with those obtained in the same seasons after winter wheat on upland that had been in cultivation about 25 years. The tests were not strictly comparable as to dates of seeding for the two locations, but the data are believed to represent the possibilities fairly well in each case.

TABLE 16.—*Yields of Sudan-grass hay on bottom land after alfalfa and on upland after winter wheat, 1927 and 1928*

| Year | Acre yield (tons) | | |
|---|---|---|---|
| | On bottom land after alfalfa | | On upland after winter wheat |
| | First year | Second year | |
| 1927 | 4.39 | 4.11 | 3.60 |
| 1928 | 4.40 | 3.92 | 3.48 |
| Average | 4.40 | 4.02 | 3.54 |

COMPARISON OF SUDAN GRASS WITH SORGO AND MILLET FOR HAY PRODUCTION

Sudan grass, sorgo, and millet compete with each other as annual crops for hay production, and it is therefore of interest to compare their yields and rates of growth. The data obtained from normal dates of seeding are assembled in table 17. These dates on the average were Sudan grass June 4, sorgo June 5, and millet June 7. The crops were all seeded in close drills under comparable soil conditions.

TABLE 17.—*Comparison of hay yields and season (time required for hay production) of Sudan grass, Red Amber sorgo, and two varieties of millet from normal dates of seeding for 1914-28*

| Year | Hay per acre | | | | Season [1] | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Sudan grass | Red Amber sorgo | Goldmine millet | German millet | Sudan grass | | Red Amber sorgo | Goldmine millet | German millet |
| | | | | | First cutting | Second cutting | | | |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Days* | *Days* | *Days* | *Days* | *Days* |
| 1914 | 3.80 | 3.98 | 3.08 | 3.11 | 65 | 59 | 108 | 64 | 68 |
| 1915 | 4.26 | 6.91 | 1.98 | 3.31 | 78 | 50 | 106 | 52 | 66 |
| 1916 | 2.07 | 1.83 | 1.25 | 1.17 | 58 | 65 | 98 | 59 | 59 |
| 1917 | 2.02 | 2.67 | 1.86 | 1.95 | 103 | ------- | 123 | 68 | 70 |
| 1918 | 1.96 | 3.16 | 1.69 | 1.85 | 59 | ------- | 88 | 67 | 73 |
| 1919 | 2.20 | 3.10 | 1.16 | 1.68 | 57 | 56 | 73 | 53 | 73 |
| 1920 | 3.14 | 4.17 | 2.52 | 2.09 | 58 | 70 | 97 | 66 | 80 |
| 1921 | 2.81 | 3.37 | 2.54 | 2.41 | 63 | 61 | 94 | 62 | 75 |
| 1922 | 3.39 | 3.51 | 3.05 | 3.25 | 51 | 53 | 86 | 50 | 60 |
| 1923 | 1.70 | 2.32 | 1.55 | 1.27 | 60 | 79 | 100 | 62 | 65 |
| 1924 | 2.08 | 2.65 | .77 | 1.86 | 62 | 54 | 108 | 63 | 65 |
| 1925 | 3.04 | 4.42 | 3.02 | 3.00 | 70 | ------- | 92 | 65 | 77 |
| 1926 | 1.13 | 1.21 | .73 | .67 | 67 | ------- | 84 | 67 | 67 |
| 1927 | 3.60 | 4.63 | 1.75 | 2.09 | 67 | 29 | 106 | 63 | 77 |
| 1928 | 3.48 | 4.68 | 1.73 | 2.08 | 80 | ------- | 80 | 59 | 75 |
| Averages | 2.71 | 3.51 | 1.91 | 2.12 | 67 | 58 | 96 | 61 | 70 |
| Relative yields [2] (percent) | 77 | 100 | 54 | 60 | ------- | ------- | ------- | ------- | ------- |

[1] Days from seeding to first cutting and days from first cutting to second cutting. There was no second cutting of Sudan grass in 4 of the years and only one cutting each year for sorghum and millets.
[2] Relative yields, taking Red Amber as 100 percent.

Sorgo leads decidedly in tonnage, but is much the coarsest (fig. 19). This coarseness is not an objection, however, and the hay is excellent, especially for wintering cattle. To be fed effectively, sorgo hay requires a protein supplement, such as 1 pound of cottonseed cake or 3 to 4 pounds of alfalfa hay daily per head. It also leads in the following: Ease in obtaining a good stand, resistance to drought and

insects, and withstanding deterioration in field and stack. Sorgo requires the longest growing season, but this is not an objection at the normal date of seeding; in fact, it is economical to secure the entire season's growth in one cutting.

Sudan grass is finer stemmed and therefore subject to less waste in feeding. When cut relatively early, about the first head stage, its protein content is sufficient so that cattle may be wintered on this hay alone as successfully as on sorgo hay plus the protein supplement. Sudan-grass hay probably has the widest range of usefulness among all kinds of livestock, and the grass excels as a pasture crop. Objections to Sudan grass have been the high price of seed, lack of resistance to grasshoppers and chinch bugs, and the expense of two cuttings. In 10 of the 15 years there was a second cutting, which was usually very light.

All things considered, millet is the least valuable crop of the three, and its continuous decline in acreage since 1885 seems justified.

FIGURE 19.—Comparison of Sudan grass and Early Sumac sorgo seeded in close drills for hay production.

Millet makes the lowest yields of the group, but as it sends up no moisture-consuming second growth, dying as soon as it is mowed, it has the advantage of permitting the farmer to follow the crop with winter wheat. It must, however, be cut at the proper time, that is, before seed has formed. It has certain limitations as a feed, especially for horses.

Comparisons of Sudan grass, Red Amber sorgo, and some variety of millet seeded about July 1 for hay production were conducted regularly for the period 1921 to 1928, inclusive. The actual dates ranged from June 24 to July 4, depending on soil conditions. The seedings were made on land that had been fallowed throughout the spring months, a very important factor in the success of late catch crops. Such soil conditions often exist where a row crop of corn or sorghums has failed to produce a stand or has been destroyed by insects or storms. Late-prepared land or fields on which small grain has just been harvested are likely to result in failures when seeded

about July 1. It is necessary to have an abundant supply of stored moisture and a good tilth of surface soil, such as are obtained by a spring fallow.

The results from July 1 seedings are shown in table 18. The plants reached a satisfactory hay stage regularly, and in some cases the hay was of better quality than that obtained from normal dates of seeding. The July 1 seedings are inclined to grow off rapidly and continuously with the minimum of interruption from drought, and they incline especially to production of succulent leafy forage. July 1 is about the latest practical date for seeding sorgo, but Sudan grass and millet may be sown up to July 15 in most seasons.

TABLE 18.—*Comparison of hay yields and season (time required for hay production of July 1 seedings of Sudan grass, Red Amber sorgo, and millet in close drills 1921–28*

| Year | Sudan grass | | Red Amber sorgo | | Millet [1] | |
|---|---|---|---|---|---|---|
| | Season | Yield per acre | Season | Yield per acre | Season | Yield per acre |
| | *Days* | *Tons* | *Days* | *Tons* | *Days* | *Tons* |
| 1921 | 75 | 1.83 | 89 | 2.89 | 70 | 1.32 |
| 1922 | 70 | 1.51 | 76 | 2.63 | 60 | 1.47 |
| 1923 | 58 | 1.35 | 58 | 1.66 | 50 | 1.24 |
| 1924 | 57 | 2.22 | 99 | 3.61 | 60 | 1.79 |
| 1925 | 65 | 2.73 | 65 | 3.59 | 65 | 2.84 |
| 1926 | 65 | 1.20 | 78 | 1.25 | 64 | .52 |
| 1927 | 59 | 4.15 | 104 | 5.00 | 73 | 1.92 |
| 1928 | 59 | 2.48 | 77 | 4.72 | 62 | 1.54 |
| Average | 64 | 2.18 | 81 | 3.17 | 63 | 1.58 |

[1] White Wonder, 1921 and 1922; Siberian, 1923; Goldmine, 1924 to 1928.

The data obtained from normal and late seedings of Sudan grass, sorgo, and millet may be examined from the standpoint of rate of growth as well as for total amount of hay produced. The number of pounds of air-dry hay per acre produced per day of growing season is presented in table 19, both for the normal and the July 1 dates of seeding. The results indicate that the second cutting of Sudan grass grew very slowly as compared with the first, also that the differences between Sudan grass, sorghum, and millet were less on a daily than on a seasonal basis.

TABLE 19.—*Weight of hay produced per day by Sudan grass, sorgo, and millet in close-drilled seedings at two different dates for the years indicated*

| Normal date of seeding (average June 4 to 7) | | Late date of seeding (average July 1) | |
|---|---|---|---|
| Crop | Daily production per acre, 1914–28 | Crop | Daily production per acre, 1921–28 |
| | *Pounds* | | *Pounds* |
| Sudan grass, first cutting | 65.4 | Sudan grass | 68.1 |
| Sudan grass, second cutting [1] | 26.9 | Red Amber sorgo | 78.3 |
| Red Amber sorgo | 73.1 | Millet [2] | 51.0 |
| Goldmine millet | 62.6 | | |
| German millet | 58.6 | | |

[1] Average of 10 years, when a second cutting was made.
[2] White Wonder, 1921 and 1922; Siberian, 1923; Goldmine, 1924–28.

### SEED PRODUCTION

Experiments with Sudan grass in different widths of rows for seed production were conducted during the period 1913–23. The plots were surface planted with a grain drill on land intensively prepared, often including fall plowing or fall listing in the preparation. The grass was seeded from May 23 to June 6, except in 1915 and 1923 when wet weather delayed the work. Good stands and satisfactory vegetative growth were generally obtained, but the seed yields were usually disappointing. Drought in July and August was a limiting factor in seven seasons, and wind shattering the seed heads reduced yields in at least 6 years. In four seasons, when the crop was injured in midseason by drought or hail, it approached maturity late in September when the nights were cold; ripening therefore was very slow. In nearly all seasons the prolific tillering of the Sudan grass, accompanied by a long-continued period of heading, resulted in very uneven maturity. Less than half the seed was ripe enough to cut at any one time, and if harvest was delayed, the early heads were usually subject to severe shattering. In 1921, the only season of really satisfactory results, the plots were seeded May 21 and harvested August 18. Drought checked vegetative growth after the main heads came out and encouraged them to mature rapidly and evenly. The month also was one of continuously low wind velocity.

The results given in table 20 show that yields from 486 to 602 pounds of seed per acre were produced in the best season, 1921. In four other seasons the yields ranged from 200 to 400 pounds. The averages, around 200 pounds, are too low to be profitable at the prices now received for seed.

TABLE 20.—*Seed yields with accompanying yields (air-dry) of the total crop of Sudan grass grown in rows variously spaced, 1915–23*

| Year | Seed yield per acre from row widths of— | | | Total crop, yields per acre from row widths of— | | |
|---|---|---|---|---|---|---|
| | 24 inches | 40 inches | 80 inches | 24 inches | 40 inches | 80 inches |
| | *Pounds* | *Pounds* | *Pounds* | *Tons* | *Tons* | *Tons* |
| 1915 | 90 | 75 | 45 | 2.93 | 3.21 | 2.36 |
| 1916 | 33 | 33 | 28 | 1.19 | 1.04 | .85 |
| 1917 | 300 | 260 | 260 | 3.06 | 3.13 | 2.32 |
| 1918 | 62 | 73 | 92 | 1.14 | 1.28 | .98 |
| 1919 | 209 | 217 | 203 | 2.30 | 2.20 | 2.13 |
| 1920 | 368 | 404 | 319 | 2.50 | 2.39 | 2.19 |
| 1921 | 507 | 602 | 486 | 1.83 | 1.98 | 1.68 |
| 1922 | 249 | 294 | 318 | 1.59 | 1.59 | 1.45 |
| 1923 | 0 | 0 | 0 | 1.88 | 2.00 | 1.67 |
| Average | 202 | 217 | 195 | 2.05 | 2.09 | 1.74 |

When the prices of seed were as high as they were prior to 1915, a good profit was realized by most growers irrespective of yields. The Sudan-grass seed industry now seems stabilized at prices usually less than 5 cents a pound to the grower, and seed production is therefore profitable only to growers who, by reason of favored conditions and special skill, can produce high yields at a minimum cost. Sudan-grass seed growing is now of very limited interest to most farmers in western Kansas under dry upland conditions. Numerous small fields for this purpose are noted in years when the winter-wheat crop

has failed and left more land than usual for spring crops, but low prices usually follow these increased acreages.

Sudan-grass straw left after threshing has considerable feeding value, but is so coarse and contains so much crude fiber that it compares rather unfavorably with hay cut at or before the heading period. The quantity of straw to be expected from a seed crop is indicated by the yield of the total crop in table 21. The total crop minus the seed yield would represent the approximate yield of straw.

### SORGO-SUDAN GRASS HYBRIDS

Several natural hybrids of Red Amber and Sudan grass were grown in 1915 and 1916. Hybrids of these same two plants were later received from H. Willis Smith under the names Ford sorgo and Supersorghum. A Sudan-Freed sorgo hybrid was received from Smith under the name Kansarita. Sudamber and Sudurcane were Black Amber crosses with Sudan grass received in 1919 from M. G. Mueller, Colome, S.Dak. These hybrids were intermediate between the sorghum and Sudan grass in yield and coarseness, but inferior to either in forage quality and were not promising.

Sudan-sorghum was grown in 1922 under F.C. 04263 and F.C. 11530, also under the name Mammoth Forage, and in 1923 it was grown under the name of Sweet Sudan. In all cases it stooled and headed much like Sudan grass, but its stems were as coarse as those of close-drilled sorghum.

### MISCELLANEOUS GRASS SORGHUMS

Tunis grass (*Sorghum virgatum*) (S.P.I. 26301), which was grown at Hays from 1913 to 1915, is an annual closely related to Sudan grass. It was introduced into the United States from Algiers, Algeria, in 1909,[8] but has never reached commercial importance because it shatters its seed too quickly, is less leafy than Sudan grass, and tillers less freely. In addition, the awned seed is difficult to feed through a grain drill. Tunis grass is about 5 days earlier and makes a more vigorous early growth than Sudan grass. It is slightly more resistant to grasshopper attacks and to the red-spot leaf disease.

Several crosses of Tunis grass and sorgo were grown in 1916, but they were not promising enough at Hays to receive more than a preliminary test in cultivated rows. Those tested were F.C. 7471–1–3, 7475–4, and 7476–2–7.

At Hays a cultivated row of Tunis grass grew 3 to 4 feet tall, sent up a few heads, and retained some of its leaves in the very dry grasshopper year of 1913, when most other plants in the nursery were entire failures. A close-drilled plot of one twentieth of an acre dried up with scarcely a foot of growth in the main body of the plot.

Tunis grass and Sudan grass were compared in 40-inch rows at Hays in 1914 and 1915, two rather favorable seasons. The high yields in 1914 were due in part to seeding on fallowed land. Abnormal rainfall in 1915 was a favorable factor. Two cuttings were made each season and the average yields were: Tunis grass 4.18, Sudan grass 4.42 tons per acre of air-dry hay.

The grass sorghums tested in 1925 were as follows: Perennial Sudan, S.P.I. 56801, from Rhodesia grew 5 to 8 feet tall, was coarse

[8] VINALL, H. N., and GETTY, R. E. Op. cit. (See footnote 7, p. 44.)

and stemmy and did not survive the winter. Black Sudan grass (*Sorghum versicolor*), S.P.I. 56802, from Rhodesia grew only 3 feet tall and proved to be a poor forage type, with freely shattering seed. Black Sudan grass, S.P.I. 61683, from South Africa grew only 2 feet tall, was not promising and was similar to S.P.I. 56802. Tabucki grass (*S. verticilliflorum*), S.P.I. 61674, from South Africa grew 6 feet tall with stems one half inch or more in diameter, each plant with 12 to 15 tillers lacking in leafiness. It did not mature seed at Hays.

## MISCELLANEOUS GRASSES

About 50 grasses, including both annuals and perennials, were grown at Hays, usually in nursery rows, for one or more seasons. Most of them are definitely unsuited to dry-land conditions, and none has been recommended for farm use. Bromegrass, apparently as good as any of these grasses, usually made a good normal growth 2 to 3 feet tall in cultivated rows or hills, but in close-drilled seedings on the dry-land agriculture project it showed up very poorly.

### BROMEGRASS

Bromegrass (*Bromus inermis*) received the most thorough test of the perennial grasses at Hays. A general field of 10 acres, partly on bottom land and partly on upland, was successfully seeded to bromegrass about 1902, and was promising during a few wet years early in its growth, but it produced very little growth later on because of drought and diminishing stands. The last of this grass was plowed up in 1913, and no other seedings of it on a field scale have been attempted.

The most extensive plot tests of bromegrass at Hays have been conducted in rotation no. 141 on the dry-land agriculture project, which was begun in 1906 and is still continued. This is a 6-year rotation of (1) oats, (2) corn, (3) winter wheat, and (4–6) bromegrass. The bromegrass is seeded in early spring at sowing time for oats on fall-plowed wheat stubble. It is usually drilled at 10 to 25 pounds to the acre, but often fails to produce a stand. In 11 years out of 22, 1906–27, a satisfactory stand was not secured during the first season that the plot was due to be in bromegrass. In 6 years a stand had not been established the second year, and in two cases a plot went through the full 3-year period without the establishment of a stand. It requires 1 to 3 clippings the first season to keep down weeds. It also requires several applications of poison to prevent grasshopper damage, and even if a stand is secured there is no return the first year. Growth sufficient to harvest for hay was not obtained from second- or third-year stands in the first 10 years of this test. Hay yields were obtained in 1916, 1919–22, and 1925–27. During these 8 years the yields varied from 0.27 to 1.10 tons annually, with an 8-year average of 0.59 ton per acre. There is not much chance of sufficient growth to cut for hay after the third year. An attempt to maintain a permanent stand of bromegrass around the laboratory was eventually given up in favor of buffalo grass.

Bromegrass is one of the earliest grasses to start growth in the spring, and an established stand would furnish a few weeks of excellent early pasturage; this possibility, however, does not warrant attempts to grow the crop. While bromegrass is fairly drought-resistant, it suffers too much from heat at Hays. It has been grown by farmers

with success farther northeast in Kansas, notably in Washington County.

Bromegrass was grown successfully in hills and cultivated nursery rows at Hays, along with other miscellaneous grasses, for several years, but from an economic standpoint it is a failure under field conditions.

#### JOHNSON GRASS

Johnson grass (*Sorghum halepense* var. *miliformis*), S.P.I. 34704, was grown in a single row test in 1913, but when the field was fall listed none survived the winter. Seeded again in another row in 1914, it survived one winter when undisturbed by tillage, but died out the second winter following deep plowing in December. Johnson grass was inferior to Sudan grass in forage quality and yield. While Johnson grass, because of its creeping rootstock habit, is a serious perennial weed pest in the South, it apparently can be controlled easily in the latitude of Hays by fall plowing.

#### FUNDI

Fundi (*Digitaria exilis*) is an annual and a close relative of crabgrass. It was introduced from Africa, where it is said to have been cultivated considerably by the natives as a grain crop. Preliminary tests of it at McNeill, Miss., and Lubbock, Tex., in 1920 indicated much promise for it as hay and perhaps as pasture. It was then grown at Hays in 1921 and 1922, both in close drills and in cultivated 40-inch row plots of one twentieth of an acre each. It was seeded rather shallow, with a grain drill, on well-prepared land and with favorable conditions prevailing. The seeding dates were May 23 and June 7 for the respective years, and in each case the grass required 2 to 3 weeks to come up. Meanwhile, pigweeds came up, which would have smothered the fundi except for clipping in 1921 and hand weeding in 1922. The grass reached a height of about 8 inches in both seasons, while sorgos, Sudan grass, and millet were making excellent yields under the same conditions. Fundi would not even have made good pasture at Hays, for the plants were shallow rooted and would have been pulled up or tramped out easily.

#### RYEGRASS

Plot tests of the following ryegrasses (*Lolium* sp.) were attempted in 1924: F.C. 2361, Italian ryegrass; F.C. 2362, perennial ryegrass; F.C. 2379, Westerwold ryegrass; F.C. 2383, Wimmera ryegrass; and F.C. 2425, Tystofte Danish ryegrass. Uneven stands were obtained, and the grasses suffered from drought and weed competition, produced very little, and did not survive the dry winter. Square-rod plots of these ryegrasses seeded in 1925 were equally poor. Similar land, however, produced from 2 to 3 tons of Sudan grass per acre.

#### NURSERY EXPERIMENTS

Attempts to establish a nursery in 1913, principally of *Bromus* and *Agropyron* selections, were unsuccessful, due to insects and severe drought. In 1914, nursery rows of the following were established: *Agropyron elongatum*, S.P.I. 25084; *A. intermedium*, S.P.I. 25085; *A. tenerum*, S.P.I. 23264; *Agrostis alba*, S.P.I. 25638 and 34887;

*Bromus inermis*, F.C. 468, 469, 473, 481, 492, and 1441; *Elymus sibiricus*, F.C. 6903 and S.P.I. 24470; *Lolium italicum*, S.P.I. 34277; *L. perenne*, S.P.I. 34278; *Phleum pratense*, S.P.I. 29492; *Festuca* sp., S.P.I. 32387. Seeded May 11, in cultivated rows 2 feet apart, all of these made 8 to 10 inches of growth in 1914, which was a normal season. *Lolium italicum* and *L. perenne* did not survive the winter. The others made a remarkable growth (30 to 50 inches) in the very wet season of 1915. The *Bromus* selections varied as to erectness and spreading habit, showing the possibilities and the need for selection work. Bromegrass was rated first in the above collection of grasses, both as a hay and a pasture possibility. *A. tenerum* was rated second as a pasture prospect. *A. elongatum* and *A. intermedium* were heavy-yielding hay types. Timothy and redtop made a growth similar to that made by the grasses in the eastern United States. Such results, of course, far exceed any possibilities the grasses would have under normal field conditions.

The following grasses were established in the nursery by setting out rooted plants in the springs of 1926 and 1927. This is a much more satisfactory method than attempting to start a nursery direct from the seed, especially if the seed is of low germination and the land foul with weeds.

*Aeluropus littoralis*, S.P.I. 61388.
*Agropogon strigosum*, S.P.I. 66341.
*Agropyron repens*, S.P.I. 58866.
*Agropyron ciliare*, S.P.I. 64765.
*Ampelodesma bicolor*, S.P.I. 60319.
*Arundinella villosa*, F.C. 04141.
*Brachypodium japonicum*, S.P.I. 59353.
*Bromus erectus*, S.P.I. 68066 (from seed).
*Bromus* sp., S.P.I. 64914.
*Calamagrostis epigejos*, S.P.I. 57279.
*Calamagrostis* sp., S.P.I. 68408.
*Eragrostis fascicularis*, S.P.I. 54404.
*Festuca interrupta*, F.C. 03281.
*Festuca ovina sulcata*, S.P.I. 57517.
*Heteropogon contortus*, F.C. 04615.
*Koeleria cristata*, F.C. 04626.
*Nasella* sp., F.C. 04682.
*Panicum repens*, S.P.I. 51158.
*Poa australis*, S.P.I. 56910.
*Poa* sp., S.P.I. 53117.
*Sorghastrum* sp., F.C. 05049.
*Sporobolus* sp., S.P.I. 58779.
*Stipa pubescens*, S.P.I. 56569.
*Stipa papposa*, F.C. 05040.
*Stipa* sp., F.C. 03074.
*Trisetum carpaticum*, S.P.I. 59700.
*Zoysia japonica*, S.P.I. 29016.

Two aggressive, rapidly spreading grasses, *Agropyron repens* and *Calamagrostis epigejos*, have attracted favorable attention as pasture possibilities. Work with these and several of the next most promising types has been continued at Hays under varied conditions. The collection as a whole, aside from the two just mentioned, has been disappointing. The following were annuals, under Hays conditions, and of no particular interest:

*Arundinella villosa*, *Heteropogon contortus*, *Nasella* sp., *Stipa papposa*, *Sorghastrum* sp., *Panicum* sp., *Poa* sp., *Eragrostis fascicularis*, *Stipa* sp., *Sporobolus* sp., *Stipa pubescens*, *Ampelodesma bicolor*, and *Bromus* sp.

*Festuca interrupta*, *Koeleria cristata*, *Brachypodium japonicum*, *Poa australis*, and *Festuca ovina sulcata* were wiry, scanty-leafed bunch grasses. *Aeluropus littoralis* (died 1928) and *Zoysia japonica* made only a small growth.

Five others are of some promise as follows: *Stipa* sp., F.C. 03074, competing with bromegrass as a hay grass; *Agropyron ciliare*, S.P.I. 64765, and *A. strigosum*, S.P.I. 66341, vigorous, erect, and apparently palatable pasture or hay types during early spring, but nonspreading in habit; *Bromus erectus*, S.P.I. 68066, a flat-growing pubescent-leafed bromegrass, possibly a pasture type, but likely inferior to regular *B. inermis; Calamagrostis* sp., S.P.I. 68408, a fine-stemmed vigorous type with abundant tender leaves, best quality in the whole

collection, but its usefulness is doubtful on account of its nonaggressive habit.

The problem of securing a perennial grass suitable for seeding for hay or pasture under dry-land conditions has been of much interest ever since the native sod was extensively broken up. While it has been solved to some extent in the northern half of the Great Plains, the demand is still unsatisfied in the Hays section, and it is doubtful if any of the foregoing grasses will withstand successfully the adversities of general field and pasture use. In the opinion of the writer, it is more practicable to get land back into pasture in this section through the use of sweetclover than through the use of tame grasses. Interesting possibilities exist, however, in reestablishing buffalo-grass sod alone or in combination with sweetclover, and these possibilities are now being investigated at Hays.

## MILLET

### NURSERY EXPERIMENTS

Nursery work with millet included the testing of (1) 19 selections received from Akron, Colo., when the Hays project was establishd, and (2) introductions from foreign countries. A total of 127 lots were grown one or more seasons,[9] and detailed notes were included in the annual reports with respect to the more important vegetative and head characters. The results are negative from the standpoint of developing improved varieties, but will be discussed at sufficient length to show the results obtained. Millet breeding appears to offer very little promise as compared with the breeding of other forage crops, because of the declining importance of millet and the uniformly poor forage quality of most of the introductions.

The 1913 millet nursery was destroyed by drought when the plants were a few inches tall, but in other years they had opportunity to make normal development. In 1914, Goldmine millet selections F.C. 6910 and 6913 were noted as superior in leafiness to the other lots from Akron, Colo. From 1 to 4 selections each of the varieties Proso, Kursk, Goldmine, Hungarian, Siberian, Japanese, and Common were included in the Akron collection. These tests indicated the possibility of some improvement in the ordinary varieties by selection, if the millet crop was considered of sufficient importance to warrant several years of detailed head-to-row work.

There was a wide variation among the introductions tested, but nearly all were more or less coarse stemmed, and many were deficient in leafiness. Those of sufficient leafiness to attract favorable attention were often late maturing and suffered more from drought than the earlier sorts. The introductions came largely from Manchuria, Siberia, and other sections of China and Russia, but a few were received from scattered points in Asia, Europe, and Africa. The millets of the world have been rather thoroughly studied, and apparently they are less developed as forage than as seed crops.

[9] The following lots were tested and detailed notes may be found in the unpublished reports for the years indicated on file in the Division of Forage Crops and Diseases:
1913, F.C. 0841, 01523, 01926, 01930, 01951; S.P.I. 18622, 20856, 22489, 27556, 27591, 27593, 27594, 27595, 27893, 27894, 27895, 28029, 28048, 28735, 28737, 29002, 29430, 29432–29436, 29628.
1914, F.C. 0841, 01523, 01926, 01930, 01951, 6904, 6906–6915, 8509–8512, 8514, 8516–8518; S.P.I. 18505, 20856, 22489, 22491, 27589, 27590, 27591, 27593–27595, 27893, 27894, 28735, 29000, 29002, 29430, 29432, 29433, 29435, 29436, 29628, 34771, 35337, 35339, 35340, 35342, 36673, 36796.
1922, F.C. 04259; S.P.I. 48091, 53947, 53948, 54438.
1924, F.C. 04259, 11536–11556, 11558–11563, 11570; S.P.I. 48091, 53947, 53948, 54438, 56399, 57684, 57867, 59328.
1925, F.C. 04259, 11536–11549, 11551–11556, 11559–11561; S.P.I. 48091, 53947, 56399, 57684, 57867, 60337, 60338, 60339, 62406, 62407, 62603, 62604, 63700.
1926, S.P.I. 62603, 63700, 64351, 65519, 65862, 65923, 65924, 66347–66365.

### VARIETY TESTS

Eight varieties of millet were included for 5 years or more in duplicate 1/20-acre plots for hay production during the period from 1914 to 1928. Seed yields were taken from the same plots from 1920 to 1928. The land was thoroughly prepared throughout the spring and the average date of seeding was June 7. The yields obtained, together with averages of the heights and of the lengths of season, are given in table 21.

Kursk and Siberian are two orange-seeded types noted for early maturity. Like common millet, they produce dependable but light forage yields and relatively high seed yields under dry-land conditions. Hungarian and Goldmine, while differing in seed color, appear practically equal in forage and seed-production habits, and intermediate in yields and maturity among the varieties here discussed. White Wonder and S.P.I. 56398 are very much alike, coarser, taller, and

FIGURE 20.—German millet (right); White Wonder millet (left). The latter, a new variety, is a heavy seed producer but not so leafy as the German.

later than the first five named. The seeds are larger, rougher, and more nearly round than the other millets grown. The plants have a longer, heavier head than most millets and lodge more readily. They are too stemmy in proportion to foliage to rank high as forage crops (fig. 20). German is also coarse, but it is much leafier and is the best millet for more humid conditions. Because it is lacking in earliness and drought resistance, it is not well adapted to the climatic conditions at Hays in most seasons.

Siberian, Common, Hungarian, and German are well-known commercial varieties. Siberian or a selected strain known as Kursk are favorites in extreme western Kansas. Common is also grown in that section to some extent. The heads of German and Common are much different in shape, but the seeds of both are light yellow, and it is very difficult to distinguish the seed of one variety from that of the other.

TABLE 21.—*Yields and agronomic data of millet varieties grown at Hays, Kans., 1914–28*

| Variety | Acre yields of air-dry hay | | | | | | | | | | | | | | | Average | | Relative yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1914 | 1915 | 1916 | 1917 | 1918 | 1919 | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Variety | Check | |
| | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Tons* | *Percent* |
| S.P.I. 56398 | | | | | | | | | | 1.88 | 0.97 | 3.00 | 0.76 | 2.37 | 2.19 | 1.86 | 1.59 | 117 |
| White Wonder | | | | | | | 3.28 | 3.00 | 2.57 | 1.45 | 1.00 | 2.91 | .77 | 2.49 | 2.15 | 2.18 | 1.96 | 111 |
| German | 3.11 | 3.31 | 1.17 | 1.95 | 1.85 | 1.68 | 2.09 | 2.41 | 3.25 | 1.27 | .86 | 3.00 | .67 | 2.09 | 2.08 | 2.05 | 1.91 | 107 |
| Goldmine | 3.08 | 1.98 | 1.25 | 1.86 | 1.69 | 1.16 | 2.52 | 2.54 | 3.05 | 1.55 | .77 | 3.02 | .73 | 1.75 | 1.73 | 1.91 | 1.91 | [1] 100 |
| Hungarian | | 2.06 | 1.27 | 1.52 | 1.64 | 1.37 | 2.28 | 2.32 | 3.01 | 1.59 | | | | | | 1.90 | 1.96 | 97 |
| Siberian | | | | | | 1.18 | 2.08 | 2.16 | 2.69 | 1.36 | | | | | | 1.89 | 2.16 | 88 |
| Common | 2.57 | 1.57 | 1.02 | 1.61 | 1.59 | 1.54 | 1.97 | 1.97 | 2.59 | 1.60 | | | | | | 1.80 | 2.07 | 87 |
| Kursk | 2.64 | 1.67 | 1.29 | 1.30 | | 1.01 | 2.01 | 2.14 | 2.89 | 1.37 | | | | | | 1.81 | 2.11 | 86 |

| Variety | Average height of plant | Average period from seeding to hay harvest | Average period from seeding to maturity | Acre yields of seed | | | | | | | | | Average | | Relative yield |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1920 | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | Actual | Check | |
| | *Inches* | *Days* | *Days* | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Bushels* [2] | *Percent* |
| Kursk | 31 | 54 | 74 | 15.4 | 22.3 | 32.8 | 12.4 | | | | | | 20.7 | 17.2 | 120 |
| Siberian | 34 | 53 | 74 | 16.2 | 22.4 | 28.0 | 9.5 | | | | | | 19.0 | 17.2 | 110 |
| White Wonder | 39 | 69 | 87 | 27.2 | 22.8 | 10.1 | 14.6 | 7.6 | 25.4 | 0 | 25.4 | 14.3 | 16.4 | 15.0 | 109 |
| S.P.I. 56398 | 35 | 67 | 85 | | | | 11.9 | 8.6 | 23.0 | 0 | 27.0 | 11.3 | 13.6 | 13.1 | 104 |
| Common | 32 | 57 | 77 | 10.8 | 18.1 | 28.7 | 11.9 | | | | | | 17.4 | 17.2 | 101 |
| Goldmine | 33 | 61 | 79 | 14.8 | 18.3 | 23.7 | 11.9 | 5.8 | 33.0 | 0 | 14.6 | 13.2 | 15.0 | 15.0 | [1] 100 |
| Hungarian | 31 | 58 | 80 | 14.6 | 13.0 | 21.3 | 11.3 | | | | | | 15.1 | 17.2 | 88 |
| German | 36 | 70 | 93 | 10.6 | 3.3 | 5.4 | 0 | 4.2 | 11.8 | 0 | 14.7 | 10.4 | 6.7 | 15.0 | 45 |

[1] Check or 100 percent yields of Goldmine for the same years in which the varieties being compared were grown.
[2] Bushel=50 pounds.

## ALFALFA

### ESTABLISHING ALFALFA ON BOTTOM LAND

Alfalfa in western Kansas is largely produced on bottom lands and is generally valued more highly than any other crop that can be grown on such land. Its success has depended largely on the ability of the long taproots to penetrate to ground water at 10 to 30 feet. During the period of rapid expansion in acreage from 1890 to 1910, no particular difficulty was encountered in establishing a stand. Then followed two of the most severe droughts in the history of this section (1911 and 1913) which, together with a heavy grasshopper infestation, destroyed many alfalfa fields. In the efforts to start alfalfa again, complaints arose even from the most experienced growers that new stands could not be obtained, especially on former alfalfa fields. Since that time the alfalfa acreage in the 46 western counties of

FIGURE 21.—A 20-year-old stand of alfalfa, showing an unsatisfactory stand. Effective methods of establishing good stands on such fields are being studied.

Kansas has declined steadily until in 1926 it was less than half that of 1910.

Other factors contributing to the decline have been the intense interest in wheat production from 1914 to 1920 and careless treatment of the alfalfa fields in the matter of cutting and pasturing.

With the founding of the Fort Hays Branch Station in 1902, alfalfa at once assumed an important place in the general bottom-land fields of the station along Big Creek, and eventually occupied more than 300 acres. About half was seeded before 1910, though one field of more than 100 acres was not sown until May 1914. Several smaller areas were put in about that time, and others as late as April 1919. From 1920 to 1928, alfalfa seedings on the station were insufficient to indicate whether any new difficulty in getting stands had arisen.

Meanwhile the older fields of the station began to thin out rapidly and by 1928 some of them had been plowed up and the others, including the 1914 and 1919 seedings, were failing.

As a result of this situation and of the growing conviction among farmers and scientific workers that the reestablishment of stands of alfalfa required detailed investigation, a new project was laid out for this purpose at the Hays station. A thin, grassy, 18-year-old field, where the water table stood at a depth of 20 to 24 feet, ample for 50 plots of one tenth of an acre each, and where the alfalfa was formerly excellent, was utilized for this test (fig. 21).

Beginning in 1926, enough land was plowed up each spring to seed 10 plots yearly from 1928 to 1932, inclusive.

The 10 treatments intervening between the plowing up of the old alfalfa and reseeding were planned as follows:

1. Sudan grass 2 years.
2. Sudan grass 1 year; fallow 1 year.
3. Kafir 1 year; fallow 1 year.
4. Corn 2 years.
5. Fallow 1 year; Sudan grass 1 year.
6. Fallow 1 year; kafir 1 year.
7. Fallow 1 year; small grain 1 year.
8. Fallow 2 years.
9. Fallow 1 year.
10. No intervening treatment.

The Sudan grass and small grains were sown in close drills and the corn and kafir in 40-inch rows. The first series of 10 plots was seeded on April 23, 1928, to Kansas Common alfalfa at the rate of 18 pounds to the acre. The season was unusually wet, and in spite of severe weed infestation fair stands were obtained from all treatments except no. 10, although the abundance of weeds necessitated reseeding nos. 1 and 7 on June 9.

On July 30, 1928, Big Creek rose and flooded this field from 1 to 2 feet deep, the water draining off within 24 hours. As soon as the land was dry enough, five plots of the second series, nos. 12, 13, 17, 18, 19, were seeded to alfalfa on August 6, instead of waiting until 1929. Excellent stands from this seeding went into the winter with a growth of 6 to 8 inches.

Practically all of the successful seedings of alfalfa recorded on the Hays station from 1902 to 1928 were made within the period from April 15 to May 15, but about once in 3 years good stands may be obtained from seedings made in August, preferably early in the month, and shortly after a good rain. If August seeding is to be attempted west of the line where alfalfa is a profitable upland crop, the land should be summer-fallowed and the seedling plants protected from grasshoppers.

#### ESTABLISHING ALFALFA ON UPLAND

Since 1906, alfalfa has been seeded at Hays each year on one or more plots in rotation no. 142 of the Division of Dry Land Agriculture. This is a 6-year rotation, consisting of alfalfa 3 years, oats 1 year, corn 1 year, and winter wheat 1 year. The alfalfa seedings have been made on fall-plowed wheat stubble on a well-prepared seed bed which was usually packed twice before seeding. Seedings have usually been made in April and in case of failure to secure a satisfactory stand have been reseeded a few weeks later, and if this failed further at-

tempts to get a stand were made in the fall. The land occupied by this rotation is some of the highest and best drained on the project, and is therefore typical of adverse rather than favorable upland locations.

The results as to stands and yields obtained are presented in table 22. A stand as tabulated here indicates that the alfalfa lived through the first season. Numerous cases are classed as failures where a satisfactory number of plants came up but died within a few months because of weeds, insects, or adverse climatic factors. From 1906 to 1913 the results were mostly negative, but from 1914 on improvement was shown, due to a more favorable cycle of seasons and to accumulated experience. More or less satisfactory stands were obtained in ordinary years, but only in very wet seasons such as 1915, 1920, 1927, and 1928 did the hay yields exceed a ton to the acre.

TABLE 22.—*Results as to stands established and yields obtained from alfalfa seedings on upland, 1906–28*

[Adapted from records of the Division of Dry Land Agriculture]

| Plot | Period in rotation assigned to alfalfa | Date stand obtained | Kind of stand | Trials made | Acre yields of hay | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | First year | Second year | Third year | Total |
| | | | | *Number* | *Tons* | *Tons* | *Tons* | *Tons* |
| A | 1906–08 | Apr. 11, 1906 | Poor | 1 | [1] | [2] | [2] | 0 |
| F | 1907–09 | None | None | 5 | [2] | [2] | [2] | 0 |
| E | 1908–10 | Apr. 16, 1910 | Thin | 5 | [2] | [2] | [1] | 0 |
| D | 1909–11 | do | do | 4 | [2] | [1] | [1] | 0 |
| C | 1910–12 | do | do | 1 | [1] | [1] | [1] | 0 |
| B | 1911–13 | Apr. 25, 1912 | do | 5 | [2] | [1] | [1] | 0 |
| A | 1912–14 | do | do | 2 | [1] | [1] | 0. 68 | 0. 68 |
| F | 1913–15 | May 12, 1914 | Good | 6 | [2] | 0. 20 | 3. 49 | 3. 69 |
| E | 1914–16 | do | do | 2 | 0. 20 | 4. 56 | . 85 | 5. 61 |
| D | 1915–17 | Apr. 17, 1915 | do | 2 | [1] | . 82 | . 10 | . 92 |
| C | 1916–18 | May 11, 1918 | do | 4 | [2] | [2] | [1] | 0 |
| B | 1917–19 | do | do | 3 | [2] | [1] | . 81 | . 81 |
| A | 1918–20 | do | do | 2 | [1] | . 77 | 1. 95 | 2. 72 |
| F | 1919–21 | May 28, 1919 | do | 2 | [1] | 1. 94 | . 97 | 2. 91 |
| E | 1920–22 | Apr. 7, 1920 | do | 1 | [1] | . 90 | . 98 | 1. 88 |
| D | 1921–23 | Apr. 2, 1921 | do | 1 | [1] | 1. 00 | . 78 | 1. 78 |
| C | 1922–24 | May 4, 1922 | Thin | 1 | [1] | [1] | 1. 10 | 1. 10 |
| B | 1923–25 | Apr. 30, 1924 | do | 2 | [2] | [1] | . 40 | . 40 |
| A | 1924–26 | do | do | 1 | [1] | . 78 | . 27 | 1. 05 |
| F | 1925–27 | Apr. 24, 1925 | do | 1 | [1] | . 33 | 1. 32 | 1. 65 |
| E | 1926–28 | Apr. 10, 1926 | Fair | 1 | [1] | 1. 15 | | |
| D | 1927–29 | Apr. 23, 1927 | Good | 1 | 1. 30 | | | |

[1] Stand present as described, but no hay worth cutting.
[2] Failure to get or maintain stand. In some cases the first seeding failed but later seedings produced a stand.

Many upland farms having areas low enough to benefit from the run-off water from adjacent land may grow alfalfa successfully, but such favored areas usually may be utilized more profitably for the production of sorghums, Sudan grass, and perhaps other crops.

### GROWING ALFALFA IN CULTIVATED ROWS

Seven unsuccessful attempts were made to establish alfalfa in cultivated rows on the Hays station during 1907-12. Agricultural authorities of that time hoped that the row method of alfalfa culture would extend the crop's usefulness throughout dry-farming sections, but the difficulties in getting stands immediately became apparent. Weed competition has been the leading cause of failure, but drought, torrential rains, soil blowing, and grasshopper attacks also have been

factors. The seven attempts were made as follows: September 28, 1907; April 27, 1908; September 7, 1908; June 17, 1909; May 17, 1910; September 1, 1911; and sometime in April 1912.

When the cooperative experimental work with the Division of Forage Crops and Diseases began in 1913, more detailed work with row alfalfa was outlined. Seedings made on April 14 and 15, 1913, were destroyed by rain and hail on May 2. As soon as dry enough, the land was cultivated lightly and harrowed on May 7, then reseeded on May 8 and 9, 1913. Excellent stands were obtained, but weeds, grasshoppers, and drought would have ruined them had not an excessive amount of effort been devoted to hand weeding and grasshopper poisoning. The alfalfa stems were bare of leaves during the late summer, but they remained green, and the plants revived promptly following the September rains. These stands were successfully maintained until the dry winter of 1916-17, when a noticeable thinning took place. The remaining plants occupied the land fairly well, however, for several years more until the dry winter of 1922-23 brought a second sharp decline in stands. Three of the four replications in this experiment were plowed up at the close of 1923, and the fourth at the close of 1927.

The experiments included cultivated rows 24, 30, 36, and 42 inches apart as compared with 12- and 6-inch drills. Four replications of the 12- to 42-inch rows were seeded in $\frac{1}{10}$-acre plots, with 6-inch drills occupying every third plot as a check. The 42-inch rows included both single and double rows, the latter consisting of two rows 6 inches apart, with 36 inches intervening for cultivation.

All plots were sown with a wheat drill, by stopping up such holes as necessary. Bran was mixed with the alfalfa seed to reduce the seeding rate. With a mixture of 2 parts of bran and 1 of alfalfa by bulk, and with the drill set to sow 2½ pecks of wheat per acre, the seeding rate for alfalfa was 12 pounds per acre, with all holes in use. The amount sown to the row remained constant, the rate, for example, in 36-inch rows being only 2 pounds to the acre.

Cultivations were given only at such depths and frequency as necessary to control weeds. All plots were often cultivated lengthwise just as weeds started in the spring, using an alfalfa renovator of the hoe-drill type. The 24- to 42-inch rows were cultivated usually three or four times a season, using sweeps or small shovels. Weed control was not difficult after the first year, but, if neglected, the vacant spaces were quickly occupied by Russian-thistles or foxtail.

Grasshopper poison had to be applied every year except one to protect the crop. The applications varied from 1 or 2 to 6 or 8 a season, thus incurring additional expense.

The alfalfa produced a first cutting regularly in June, a second cutting in half of the years, and a third one in 1915. After 1915 the alfalfa made good growth when current rainfall was plentiful, but very little during dry periods as the roots were unable to reach ground water. The plants usually showed considerable bloom by June 1 and reached full bloom between June 5 and 10. The first cuttings were made between June 7 and June 27, the average date being June 15. The first cuttings were often delayed a week or two beyond the intended time because of rain and the demands of other work.

In 1916 and 1922, with timely rainfall, the alfalfa produced a good second cutting, after which, on account of drought, it made very

little recovery. During each of these dry autumns it suffered losses of about one third of the remaining stand. By contrast, the second growth in 1918 and in 1921, almost enough for a light cutting, was not harvested, and though the winters were medium dry, no noticeable losses of stands occurred.

The alfalfa in cultivated rows was difficult to mow, as the crowns were high and many stems tended to recline. Extra guards of the type used for pea vines were often used on the mower with fair results. The wider the row interval, the greater was the difficulty in harvesting. The cultivated rows produced somewhat coarser hay than the close-drilled seedings, and the hay was sometimes dusty. These two factors were not serious, however, for upland alfalfa in this section is never very rank and coarse, and the hay gathers little dust if cultivated only in the early spring or just after a cutting.

The original plan in this row experiment was to use two replications primarily for seed production, but this idea was given up on account of unfavorable climatic conditions and insect damage. Information on the seed problem was gained mostly from 10 years of observation of an additional acre block of 36-inch rows, rather than from these plots. The wet and dry periods seldom occur at the proper time to produce a first-class crop of alfalfa seed, and, furthermore, it is very difficult to prevent grasshopper injury during the late bloom and early maturity.

TABLE 23.—*Dates of cutting and yields of alfalfa hay grown on uplands in row widths of 6 to 42 inches, 1914–27*

| Date of cutting | Acre yields of hay (tons) for row widths named | | | | | | |
|---|---|---|---|---|---|---|---|
| | 6-inch rows | 12-inch rows | 24-inch rows | 30-inch rows | 36-inch rows | 42-inch rows, single | 42-inch rows, double |
| June 11, July 17, 1914 | 1.02 | 1.16 | 1.22 | 1.18 | 1.26 | 1.02 | 1.05 |
| June 19, Aug. 4, Sept. 20, 1915 | 2.49 | 2.63 | 2.40 | 2.32 | 2.27 | 2.02 | 2.14 |
| June 16, July 7, 1916 | .65 | .63 | .56 | .53 | .58 | .62 | .57 |
| June 12, Sept. 11, 1917 | .76 | .76 | .70 | .65 | .71 | .62 | .74 |
| June 10, 1918 | .79 | .78 | .66 | .57 | .58 | .56 | .57 |
| June 17, 1919 | .64 | .62 | .36 | .40 | .36 | .33 | .41 |
| June 7, Aug. 30, 1920 | 1.06 | .92 | .94 | 1.03 | 1.02 | 1.03 | 1.12 |
| June 22, 1921 | .67 | .61 | .57 | .51 | .50 | .41 | .50 |
| June 12, July 18, 1922 | 1.81 | 1.86 | 1.62 | 1.48 | 1.49 | 1.30 | 1.46 |
| June 19, 1923 | .79 | .57 | .69 | .75 | .72 | .65 | .76 |
| June 14, 1924 | .75 | .66 | .89 | .79 | .74 | .68 | .78 |
| June 15, 1925 | .21 | .18 | .28 | .42 | .36 | .49 | .55 |
| June 8, 1926 | .39 | .27 | .42 | .50 | .52 | .47 | .52 |
| June 27, Sept. 20, 1927 | .48 | .16 | .54 | .52 | .50 | .61 | .67 |
| Average, June 15 (first cutting) | .89 | .84 | .85 | .83 | .83 | .77 | .85 |

In table 23 the data on hay production for 1914–23 are based on the averages for four replications and from 1924–27 on the one remaining replication. The 6-inch check plots for the two periods consisted of 10 and 4 years, respectively.

Very little difference in yields is shown among the different row widths for any year or in the 14-year averages. It appears that the yield is dependent on the total moisture available, irrespective of the distribution of the plants within the limits tested. In this section the close-drilled method seems preferable on account of quality of hay and economy in management.

It is evident that all methods were unprofitable in most seasons, for in only 4 years did the yields amount to as much as a ton per acre. For those 4 years, 1914, 1915, 1920, and 1922, the averages for different methods ranged from 1.34 to 1.64 tons per acre. In the same 4 years Sudan grass close-drilled at the rate of 20 pounds per acre averaged 3.65 tons per acre. For the 10 poorest years the average alfalfa yields were 0.52 to 0.61 ton and that of Sudan grass 2.26 tons per acre.

Alfalfa was tested in cultivated rows for several years prior to 1918, by seven of the best farmers in western Kansas. Four of these farmers were located in Gove County, and one each in Cheyenne, Wallace, and Stanton Counties. The writer observed the results from time to time and noted that all obtained good stands in rows 30 to 42 inches apart. They were generally well pleased with their results in 1914 and 1915, but in the 3 following years yields were low and Russian-thistles either crowded the alfalfa out or caused more trouble than the alfalfa seemed worth. The only grower of the 7 who is known to have continued growing alfalfa in rows seeded 20 acres in 32-inch rows on recently broken prairie upland in western Gove County in 1923 and 1925 and obtained results satisfactory to him by irrigating the alfalfa from a large windmill. He gets larger yields from a broadcast plot also watered from the mill but finds the row method better for the even distribution of the water. Very close attention is given to keeping the middles clean, also to destroying rabbits which, if left unchecked in winter, would soon destroy the alfalfa.

#### EFFECT ON STANDS AND VITALITY OF ALFALFA REMAINING UNCUT OR BEING HARVESTED FOR SEED

Part of a 4-acre bottom-land field of alfalfa seeded in May 1914 was used for experiments to determine the effect on the alfalfa plants of allowing them to mature seed and of leaving the fields entirely uncut for as long as 3 years. The following schedule of cuttings was carried out on duplicate plots of three-fortieths of an acre for the 3-year period 1915–17: (1) Hay each year; (2) cut for seed first year, hay second year, seed third year; (3) cut for hay first year, seed second year, seed third year; (4) no cutting first year, then cut for seed 2 years; (5) no cutting until end of third season. Plots cut for hay only were used as checks in every third plot and were harvested three times in 1915, twice in 1916, and four times in 1917. Those being left for seed were cut twice in 1915, once in 1916, and twice in 1917. The cuttings for hay were made as nearly as possible at the one third bloom stage; those for seed stood until seed had formed, though not necessarily matured.

The growth on the four plots unharvested in 1915 was so heavy that the stand was thinned, probably due to smothering through the winter, recovering slowly in the spring of 1916. The loss was estimated at one third, though enough plants remained to be considered a satisfactory stand. The two plots left uncut 3 seasons were not injured particularly by the dead vegetation, except that this attracted numerous field mice to winter there and to do noticeable but not serious injury to the alfalfa. At the close of 1917 all plots were cleared off with the intention of cutting them regularly for hay and to thus measure the effect of the previous treatments on the vitality of the plants.

The season of 1918 was relatively dry, and for the first time in this experiment the growth was exceedingly spotted, with no apparent relation to previous treatments, nor uniformity within any one plot.

The average yields of hay, in tons per acre, for 1918 following the five treatments outlined were as follows: (1) 3.29; (2) 4.26; (3) 3.49; (4) 2.18; and (5) 3.80. These differences were wholly without significance, but observations made during the experiment indicated that allowing the crop to stand beyond the hay stage appeared neither to have injured nor stimulated the vitality of the plants at any time.

### CULTIVATION OF CLOSE-DRILLED ALFALFA ON BOTTOM LAND

Cultivation of some sort had often been given to general fields of alfalfa of various ages and stands on bottom land at the Hays station during a period of several years ended in 1913. A limited amount of experimental plot work with different types of machines had also been carried on prior to this date, but the results did not warrant recommending any of the cultivation methods tried. Among the machines used were the ordinary disk, the spike disk, a spring-tooth harrow, and a patented renovator with hoe-drill type of teeth.

When cooperative work was begun with forage crops in 1913, further work on this subject was outlined. For this purpose a field of 4 acres was seeded to common alfalfa in May 1914, and a good stand was obtained. Cultivation treatments were given for the 4 years 1915–18 on duplicate three-fortieths-acre plots. On account of the lack of soil uniformity apparent in the results obtained from 1916–18, and also because of the lack of response, favorable or otherwise, to the treatments, the experiment was then discontinued. The tillage methods employed and the yields obtained are shown in table 24.

TABLE 24.—*Yields of hay from close-drilled alfalfa on bottom land under different forms of cultivation, 1915–18*

| Cultural treatment | Acre yields (tons) | | | | |
|---|---|---|---|---|---|
| | 1915 | 1916 | 1917 | 1918 | Average |
| No cultivation (check) | 4.00 | 1.75 | 1.48 | 1.37 | 2.15 |
| Double disked and harrowed in early spring | 3.59 | 2.02 | 1.65 | 1.57 | 2.21 |
| Single disked and harrowed in early spring | 3.75 | 1.97 | 1.43 | 1.43 | 2.15 |
| Single disked in early spring and after each cutting | 3.79 | 1.44 | 1.60 | 1.86 | 2.17 |
| Single disked only in early spring | 3.65 | 1.56 | 1.69 | 2.12 | 2.26 |
| Renovator with hoe-drill type of rounded shovels used in early spring and after each cutting | 3.69 | 1.80 | 1.47 | 1.14 | 2.03 |
| Same renovator as above, used only in early spring | 3.95 | 1.53 | 1.46 | 1.44 | 2.10 |
| Spring-tooth harrow with 1¼-inch teeth, used in early spring | 4.11 | 1.51 | 1.22 | 1.48 | 2.08 |
| Spring-tooth harrow with 2½-inch flat shovels, used in early spring | 4.11 | 1.58 | 1.64 | 1.82 | 2.29 |

In a relatively new thick stand like this, with no weed or grass problem involved, it is not surprising that cultivation had little effect on yields. Disking seemed to thin the stands to a limited but not injurious extent. The other forms of cultivation had no appreciable effect on the plants.

From the experience with older stands previous to 1914 and with a new stand from 1915 to 1918, it was concluded that cultivation of close-drilled or broadcast stands of alfalfa was not profitable. The best field of alfalfa yet grown on the station, 100 acres seeded in 1914, never received cultivation, but remained in first-class condition until 1927–28. When alfalfa becomes grassy, it may appear to be helped by cultivation, but generally it might as well be plowed up.

### VARIETY TESTS

Several commercial lots of alfalfa were compared in duplicate one-tenth acre plots on upland, using Kansas-grown seed of Common alfalfa as a check. One experiment was conducted in 36-inch rows, and another in close drills. About 175 small lots, including importations from many alfalfa-growing sections of the world, were also grown in nursery rows for several years.

The results of this work were negative from the standpoint of finding a variety superior to the Kansas Common alfalfa. Several commercial varieties noted for winter hardiness, such as Grimm, Canadian variegated, Baltic, and regional strains of Common from northern latitudes or high altitudes, were close rivals of Kansas Common in yields, but showed no greater longevity or other qualities to warrant paying the higher prices usually asked in this area for the seed.

#### TESTS IN 36-INCH ROWS

This experiment was sown on May 9, 1913, at 2 pounds per acre on a well-drained area adjoining the width-of-row tests and was subject to the same early difficulties with weeds, drought, and grasshoppers. The yields of Kansas Common alfalfa were taken from the width-of-row experiment. These varieties differed comparatively little in yields. Such differences as occurred seemed more largely due to inequalities of stand than to varietal characteristics. Noticeable losses of stand occurred in all varieties following the dry winters of 1916–17 and 1922–23, but the crowns of the surviving plants spread out gradually and still occupied the rows reasonably well at the time the experiment was plowed up in December 1923. Yield data are shown in table 25.

TABLE 25.—*Yields of five varieties of alfalfa grown on upland in 36-inch rows, 1914–23*

| Year | Acre yields of hay (tons) | | | | |
|---|---|---|---|---|---|
| | Kansas Common, S.P.I. 34146 | Utah Common, S.P.I. 22558 | Grimm, Dry Land 32 | Brott, Dry Land 33 | Turkestan, S.P.I. 24352 |
| 1914 | 1.26 | 0.91 | 0.94 | 0.81 | 0.76 |
| 1915 | 2.27 | 2.06 | 2.03 | 2.16 | 1.71 |
| 1916 | .71 | .80 | .72 | .67 | .63 |
| 1917 | .73 | .76 | .59 | .56 | .52 |
| 1918 | .58 | .68 | .67 | .60 | .51 |
| 1919 | .36 | .32 | .33 | .28 | .19 |
| 1920 | 1.02 | 1.19 | 1.30 | 1.20 | 1.06 |
| 1921 | .50 | .46 | .36 | .43 | .41 |
| 1922 | 1.49 | 1.39 | 1.31 | 1.49 | 1.27 |
| 1923 | .72 | .97 | .87 | .99 | .71 |
| Average | .96 | .95 | .91 | .92 | .78 |

#### TESTS IN CLOSE DRILLS

Seven varieties were included in the close-drilled variety tests of alfalfa seeded May 11, 1915. While this test was located in the same upland field as the row trials, most of the land was a little lower, especially at the north end of each series. The close-drilled experiment started out under very favorable soil conditions, a wet season following a year of fallow on one replication and of partial fallow on the other. The plots were drilled at 15 pounds per acre in rows 4 inches apart, using a regular alfalfa drill. Excellent stands were

secured and maintained for about 10 years, when they began to fail rapidly (fig. 22). Certain plots at the south end of each series were plowed up in the spring of 1927 and most of the others in the spring of 1928.

The yield data, together with the dates of cutting, are shown in table 26. The varieties are named in the order in which they occurred in the field, beginning at the north or more favorable end. Comparing each variety with its adjacent checks of Kansas Common, it is evident that there were no significant differences in yielding capacity of the varieties. But since the series as a whole averaged around a ton of clean, fine hay to the acre, with no expense after seeding except for putting up hay and for grasshopper control, the results were more encouraging than in the other upland alfalfa-growing experiments reported in this bulletin.

FIGURE 22.—Dakota Common alfalfa maintained a good stand in the row and close-drilled seedings for 10 years.

TABLE 26.—*Results of variety tests of alfalfa in close drills on upland, 1916–26*

| Date of cutting | Acre yields of hay (tons) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Canadian variegated | Kansas[1] Common | Baltic | Grimm | Kansas[1] Common | Utah Common | | Kansas[1] Common | Black Hills Common (S. Dak.) |
| | | | | | | Nonirrigated | Irrigated | | |
| June 16, July 6, 1916 | 1.17 | 1.31 | 1.50 | 1.29 | 1.20 | 1.11 | 0.96 | 1.13 | 1.09 |
| June 12, Sept. 11, 1917 | 1.49 | 1.43 | 1.29 | 1.16 | 1.15 | 1.10 | 1.10 | 1.24 | 1.12 |
| June 10, 1918 | .86 | .81 | .89 | .84 | .73 | .70 | .69 | .72 | .77 |
| June 17, 1919 | .95 | .90 | 1.06 | 1.02 | .99 | .96 | .92 | 1.05 | 1.07 |
| June 7, Aug. 30, 1920 | 1.79 | 1.70 | 2.03 | 1.79 | 1.74 | 1.50 | 1.43 | 1.55 | 1.54 |
| June 22, 1921 | .85 | .83 | .80 | .73 | .77 | .70 | .72 | .73 | .74 |
| June 12, July 19, 1922 | 1.87 | 1.98 | 2.05 | 1.85 | 1.88 | 1.75 | 1.58 | 1.71 | 1.71 |
| June 18, 1923 | 1.00 | 1.08 | 1.13 | 1.03 | 1.11 | 1.06 | 1.04 | 1.13 | 1.19 |
| June 14, 1924 | .81 | .72 | .78 | .71 | .65 | .58 | .59 | .64 | .68 |
| June 15, Aug. 17, 1925 | .99 | .96 | .87 | .65 | .68 | .62 | .30 | .19 | .18 |
| June 8, 1926 | .60 | .58 | .65 | .59 | .48 | .41 | .46 | .43 | .42 |
| Average | 1.13 | 1.12 | 1.19 | 1.06 | 1.03 | .95 | .89 | .96 | .96 |

[1] Grown as checks.

### NURSERY EXPERIMENTS

The principal nursery project undertaken with alfalfa was with regional strains collected by the United States Department of Agriculture from many parts of the world. The nursery was seeded in 1914 and 1915 on upland in rows 40 inches apart, and either 1 or 2 rods long. The seed was dropped in hills 18 inches apart, and the plants were thinned to one in the hill. Detailed records are available from 1914 to 1918 in the annual reports of the project for those years, with respect to such matters as number of plants, green weights of hay, habits of growth, survival, and value compared with that of Kansas Common alfalfa grown as a check.

The nursery included alfalfas from the following sources: Siberia, China, Turkistan, India, Turkey, Africa, Australia, Germany, Russia, Spain, Italy, France, Argentina, Ecuador, Peru, Canada, and the States of Utah, Kansas, the Dakotas, and a few others. The list included also 35 selections from the Akron, Colo., station and such varieties as Baltic, Canadian variegated, Grimm, and the yellow-flowered species, *Medicago falcata*.[10]

As a net result of this work, it was concluded that Kansas Common is as desirable as any, and superior to most varieties for conditions at Hays. It is sufficiently winter-hardy, yields with the best, and has good growth habits. Only a few lots suffered serious winter-killing, namely, those from Spain, Ecuador, Peru, Italy, and Australia. Such varieties as Grimm, Baltic, and Canadian variegated were excellent ones in these tests, but showed no qualities warranting payment of a premium for the seed. Several introduced alfalfas were coarser stemmed and less leafy than Kansas Common. The prostrate habit of the yellow-flowered ones was objectionable.

While some of the lots were probably as good as Kansas Common and excelled it in one or more particulars, the results were negative from the standpoint of bringing out any new varieties for distribution. Since this work was completed, alfalfa wilt, a bacterial disease, has become a limiting factor to alfalfa culture in eastern Kansas, though not as yet a problem in the semiarid territory.

### SWEETCLOVER

Experiments with sweetclover were conducted extensively on upland at the Hays station during 1910–28. They included: (1) Cultural requirements, with special attention to date of seeding and to use of nurse crops; (2) effect of harvesting practices on hay yields; (3) use of sweetclover as pasture, and (4) trials of varieties, mostly on a nursery-row basis. Experiments under (1) and (2) were conducted mainly on duplicate $\frac{1}{20}$-acre plots or their equivalent. Pasture data as to carrying capacity were obtained on small fields of several acres each.

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[10] Space does not permit a detailed report here on the different alfalfas grown in the Hays nursery, but a list of the serial numbers grown is given, showing the scope of the work:

F.C. 910, 914, 915–919, 923–927, 929, 930, 974, 976–985, 5701–5703, 6501, 6931–6935, 6971.

S.P.I. 3507, 3508, 9359, 9450, 12549, 12694, 12695, 13436, 13769, 13857, 13999, 14786, 16508, 17992, 18629, 18751, 19534, 19822, 19968, 20437, 20718, 20722, 20726, 20896, 20988, 21022, 21032, 21195, 21217, 21232, 21247, 21269, 21735, 22001, 22417, 22784, 22788, 22789, 22790, 22948, 23203, 23394, 23396, 23454, 23481, 23625, 23658, 23752, 24451, 24452, 24455, 24603, 24635, 24835, 24836, 24837, 25022, 25115, 25192, 25537, 25605, 25606, 25607, 25932, 26642, 27217, 27234, 27246, 27247, 27267, 27365, 27367, 27371, 27372, 28070, 29140, 29212, 29987, 33760, 34116, 35085, 35086, 35435–35445, 35451–35460, 38464, 38643, 38852.

In addition 31 lots of seed representing, for the most part, commercial varieties from different parts of the United States were included.

Except when discussing varieties, the term sweetclover as used here refers to the biennial white sweetclover, *Melilotus alba*. This species was grown in all the cultural experiments and is outstanding in commercial importance in this section.

### CULTURAL PRACTICES

The problem of obtaining a stand of sweetclover is much more difficult under dry-land than under humid or irrigated conditions. Uncertainty of germination, along with delicate early growth, has been a great handicap to farmers in establishing stands of this legume, which, in its second year, is noted for its hardiness. This difficulty is reflected in sharp advances and declines of the sweetclover acreage in the central Great Plains area. Following wet years, when new seedings are successful and old stands yield well, interest in sweetclover increases and the acreage expands. With the advent of a dry or adverse season many stands fail and interest in the crop subsides for a time.

Weather, therefore, is the most important single factor in sweetclover production in the Great Plains area and, in seasons of poor or badly distributed rainfall, causes a large percentage of stands to fail, regardless of the cultural methods used. Nevertheless, some cultural practices are very much better than others, and while good practices do not guarantee a stand of sweetclover in poor years they unquestionably reduce the mortality and practically insure a stand if the conditions are fair or better.

In 158 plantings of sweetclover at the Hays station during the period 1910–28, 88 stands were classed as good or fair at the end of the first season and 70 as poor or failures. The percentage of successes was, however, much higher toward the end of the experiments than at the beginning. During the 4 years 1925–28, 47 successes were recorded against only 7 failures. Each of the failures followed the use of a practice that was known at the time to be risky, 3 being due to August seeding, 2 to the use of wheat as a companion crop, and 2 were the result of allowing a 6-peck seeding of oats to stand too long. While it is true that the weather during this time was, on the whole, favorable, the good results can be attributed in large part to the increased skill with which the plantings were managed.

Next to weather, the most important requirement in sweetclover culture is a firm seed bed. This requirement, long recognized in the East, is doubly necessary in dry farming. Without exception, and regardless of weather or of other cultural practices, sweetclover failed at Hays when seeded on soil in a loose condition. The requirement of a firm seed bed was so obvious that proof by experiment seemed unnecessary. All experimental areas were plowed shallow, if at all, the seedings were made with a drill equipped with press wheels, and the soil was firmed with a surface packer before or after seeding, or both.

### DATE OF SEEDING TESTS

The date of seeding test has long been a standard project in agronomic work in the western United States, since success or failure of a crop frequently hinges on this point alone. Accordingly, plantings of sweetclover were made at Hays at various seasons for several years. Definite schedules of planting were adopted and seedings were made as close to those dates as circumstances permitted. In

practice the dates were often advanced or retarded a few days to allow the seed to be planted in freshly moistened earth, since it was found that when the schedule was followed arbitrarily, as in certain months of 1913, 1914, and 1916, failure often could be foreseen on account of dry surface soil.

So far as sweetclover is concerned, the calendar alone does not suffice as a guide to planting. Successes, and also failures, were obtained over a wide range of dates. Furthermore, some dates having the greatest number of successes had also the largest number of failures. At no time of the year were results either consistently good or consistently poor. Since no definite tendency is apparent, the logical conclusion is that the date of planting is less important than the other conditions of culture.

Some phases of this matter need special comment. Recently popular support has been given to the idea that the most reliable method of obtaining a stand is to sow in February, or earlier, with unscarified seed. Apparently the supposition is that this is nature's method of seeding, thus subjecting the seeds to freezing and thawing, which ruptures the hard seed coats and allows moisture to enter the seeds, permitting germination of the 30 to 90 percent of hard seeds which occur in most lots of sweetclover.

There was opportunity in these experiments for only two early seedings; both were in February and both produced good stands.

In the Great Plains, however, there is often a serious drawback to such early planting. Practically all of the soils of the Great Plains are more or less heavily infested with Russian-thistle and pigweed. When sweetclover is planted in February it starts growth at about the same time as these weeds. The combined crop makes a heavy demand on the limited soil moisture. The result then is likely to be the exhaustion of the reserve moisture by midsummer, whereupon the weeds, being hardier, gain possession, and a promising stand of sweetclover is lost.

A more practical plan appears to be to defer sowing until early or mid-April and to use scarified seed and a companion crop of spring grain. By delaying the planting a little beyond the most favorable time for the grain the latter does not make the maximum growth, yet is strong enough to take the place of weeds. Most farmers are entirely willing to sacrifice a few bushels of grain for the sake of a good stand of sweetclover.

The first 10 days of May have frequently offered the best conditions of the year for sowing sweetclover seed. By this time one or more crops of weeds could have been killed, good rains may have provided an ideal condition of surface moisture, and the ground can be worked as finely as desired and packed to minimize the risk from soil blowing. The soil is also warm enough then for the clover to start off rapidly; yet since the growth is behind that of earlier seedings, the plants do not run out of reserve moisture so early in a dry summer. May seedings should be made without a companion crop, and then only if suitable conditions are present.

June seeding is feasible only in a wet summer. July seeding offers little opportunity because of the droughty conditions usually prevalent, but late July seeding may be successful in certain seasons when August proves to be wet. Early August offers a reasonable chance of a stand about once in 3 years, depending on heavy rains just before

seeding. After late August the autumn is often too dry, and sweetclover seedlings do not make enough growth to withstand the winter.

Volunteer seedings have proved feasible for keeping a tract continuously in sweetclover. The seed germinates early and abundantly, so abundantly, in fact, that the stand often has to be thinned in May with an alfalfa renovator. These early volunteer seedings are rather likely, in dry years, to run out of moisture at midsummer, but if rainfall is ample they make more first-season growth than is generally obtained from hand seedings.

### USE OF A COMPANION CROP

The question of whether to use a companion crop (sometimes called a nurse crop) is quite as much of a problem in the Great Plains as in the East. If sweetclover is seeded in grain in the ordinary manner the latter is likely to use too much of the available soil moisture. If sweetclover is seeded alone, a weed crop arises which may use more moisture than would the grain. Furthermore, without grain there is

FIGURE 23.—The plot of sweetclover on the left was seeded March 27 without a companion crop; that on the right was seeded on the same date with 3 pecks per acre of barley.

no income from the land, since, except in unusual years, sweetclover does not make enough growth on dry land the first year to harvest.

In order to determine which, if any, grain to use, a series of tests with barley and oats was conducted at the Fort Hays station from 1915 to 1928. The results of these tests are shown in table 27. Winter wheat, the leading cereal crop of the section, was not used, because abundant practical experience had demonstrated that wheat is a very poor companion crop.

Winter wheat begins rapid growth early in the spring and, even when a thin stand, it soon becomes too rank and exhaustive of moisture to permit young sweetclover to survive. Spring grains, such as oats and barley, not only have a lighter, more open habit of growth, but the growth can be restrained by late seeding. A restrained crop of barley or oats is a real companion crop (fig. 23). Its growth is reduced to a point where it does not injure the sweetclover, yet it is large enough to suppress weeds. The grain yield of a restrained crop is lessened from 10 to as much as 50 percent, but this is usually considered worth while if a stand of sweetclover can be obtained thereby.

TABLE 27.—*Tests for stand of sweetclover grown with and without a companion crop, 1915–28*

| Preceding crop | Date of seeding | Companion crop of— | | | | | | No companion crop | |
|---|---|---|---|---|---|---|---|---|---|
| | | Barley | | | Oats | | | | |
| | | Rate of seeding | Early stand | Final stand | Rate of seeding | Early stand | Final stand | Early stand | Final stand |
| | | *Pecks* | | | *Pecks* | | | | |
| Fallow | Apr. 15, 1915 | 4 | Good | Good | 6 | Good | Good | Good | Good. |
| Do | Apr. 23, 1921 | 7 | do | do | | | | do | Do. |
| Do | Apr. 16, 1926 | 3 | Fair | do | 3 | Good | Good | do | Do. |
| Do | do | 6 | Poor | Fair | 6 | Fair | Fair | | |
| Do | Mar. 27, 1927 | 3 | Fair | Good | 3 | do | Good | Fair | Good. |
| Do | do | 6 | do | do | 6 | do | Fair | | |
| Do | Apr. 13, 1928 | 3 | Good | Fair | 3 | Good | None | Good | Good. |
| Do | do | 6 | do | do | 6 | do | do | | |
| Total, good or fair number | | | 7 | 8 | | 7 | 5 | 5 | 5 |
| Total, poor or none number | | | 1 | 0 | | 0 | 2 | 0 | 0 |
| Legumes | Apr. 14, 1916 | 3 | Good | Good | 5 | Good | Good | Good | Good. |
| Do | Apr. 20, 1917 | 3 | Poor | None | 3 | Poor | None | Poor | None. |
| Do | May 5, 1917 | 3 | Good | do | 5 | Good | do | Good | Do. |
| Do | Mar. 25, 1918 | 4 | do | do | 6 | do | do | do | Do. |
| Do | Apr. 18, 1918 | 4 | Fair | do | 6 | Fair | do | None | Do. |
| Do | Apr. 15, 1919 | | | | 6 | None | do | do | Do. |
| Do | May 2, 1919 | | | | 6 | do | do | do | Do. |
| Do | May 16, 1919 | | | | 6 | do | do | do | Do. |
| Do | Apr. 15, 1920 | 4 | Good | None | | | | Good | Fair. |
| Do | Apr. 30, 1920 | 4 | do | do | | | | do | Do. |
| Do | Apr. 20, 1922 | 6 | Poor | do | | | | Poor | None. |
| Total, good or fair number | | | 6 | 1 | | 4 | 1 | 5 | 3 |
| Total, poor or none number | | | 2 | 7 | | 4 | 7 | 6 | 8 |
| Sorghum | Apr. 11, 1924 | 3 | Good | Good | 3 | Good | Good | Good | Good. |
| Do | do | 6 | do | Fair | 6 | do | Fair | | |
| Do | Mar. 27, 1925 | 3 | Fair | Good | 3 | Fair | Good | Good | Good. |
| Do | do | 6 | do | do | 6 | do | do | | |
| Do | Apr. 16, 1926 | 3 | do | do | 3 | do | do | Good | Good. |
| Do | do | 6 | Poor | Fair | 6 | Poor | Fair | | |
| Do | Mar. 27, 1927 | 3 | Good | Good | 3 | Good | Good | Good | Good. |
| Do | do | 6 | do | do | 6 | do | Fair | | |
| Do | Apr. 13, 1928 | 3 | do | do | 3 | do | Good | Good | Good. |
| Do | do | 6 | do | do | 6 | do | do | | |
| Total, good or fair number | | | 9 | 10 | | 9 | 10 | 5 | 5 |
| Total, poor or none number | | | 1 | 0 | | 1 | 0 | 0 | 0 |

All experiments were handled to promote the welfare of the sweetclover rather than that of the cereal. However, the cereals were given every reasonable chance by the use of the earliest and best-adapted varieties. The soil was prepared as shallow and as firmly as practicable and the companion crop drilled first. The sweetclover was drilled immediately afterward, as shallow as possible, and the ground was thoroughly packed. The rate of seeding of the companion crop varied from 3 to 7 pecks per acre; the rate for the sweetclover was 20 pounds per acre except in 1915 and 1919, when 25 and 12 pounds, respectively, were used.

Barley as a companion crop showed an advantage over oats in greater openness of growth and in earlier maturity. A half seeding of barley often permitted a decidedly better start and a more even

final stand of the sweetclover than did the full rate of seeding. All the companion-crop treatments had an increasingly depressing effect on the growth of the sweetclover after the first week or two. The grain was mowed or bound at or just before maturity, leaving a 6-inch or 8-inch stubble, except in 1916 and 1918, when it was mowed more closely. With the higher stubble the clover was left almost unclipped, although in a critical condition temporarily because of dry soil and exposure to the sun. If the clover survived until a fair rain, it seemed to stand any sort of drought thereafter.

Companion crops were hardly profitable in themselves when seeded sufficiently late or sufficiently thin to allow the sweetclover a good chance. Hay yields of the companion crop were generally recorded, the average for 26 seedings of barley being 1.03 tons and for 23 of oats 1.09 tons per acre. From this it appears that a companion crop under dry-land conditions should not be used unless it seems likely to use less moisture than would a crop of weeds. Better than either a companion crop or weeds is to seed alone after one or more crops of weeds have been killed.

Seeding sweetclover without a companion crop usually resulted in severe competition from pigweeds, especially if the planting followed legumes or fallow. If the planting followed sorghum, weed competition was likely to be less severe than following legumes. In such cases the weeds were pigweed, Russian-thistle, and volunteer sorghum. While the weeds and spring grains grew less rapidly after sorghums, the sweetclover grew best on this land, evidently because the soil was firm. In dry seasons the sweetclover had a better chance on sorghum land than on any other plots.

On the whole, cultural methods had less influence on the growth of sweetclover than did the weather. In good seasons nearly all methods succeeded. In poor seasons all but the best methods failed. Perhaps the most practical method, all things considered, was to seed late with a thin seeding of barley on land that had previously been in sorghum.

### HAY YIELDS AND EFFECT OF CUTTING

The yields of sweetclover hay for both years of growth have been obtained whenever possible each year from 1913 to 1928. The absence of yields for certain years is due to failures to get stands or to lack of sufficient growth in the first year to warrant cutting. The data obtained with respect to the first-year and second-year cuttings are shown in separate tables.

#### FIRST-YEAR CUTTING

Sweetclover hay production in the first season has not been encouraging. In only 7 out of 16 years was any cutting possible, and then only because of abnormal circumstances. In 1914 a 24-inch row method yielded 0.59 ton per acre, but row planting is impracticable because it requires hand weeding. The seedings of 1915 produced 1.26 tons per acre, but had the double advantage of being on fallow land and of having a very wet season. In 1918 and 1922 early spurts of growth produced a cutting, but the plants died later. Environmental conditions of 1925 duplicated those of 1915—a wet season with one replication on fallow and the other after cowpeas. Excessive moisture and volunteer stands accounted for excellent growth in 1927 and 1928, the yield of 1.55 tons in the latter year being the heaviest during the entire period. During the 16 years no hay yields with

stands surviving were produced by close drilled or broadcast sweetclover spring seeded on continuously cropped land, though it seems possible that about half a ton to the acre could have been taken from some of the plots seeded on sorghum land during the favorable cycle from 1924 to 1928.

Sweetclover was cut low for hay at different stages of the first season's growth in 1925, 1927, and 1928, and cuttings leaving a 6-inch to 8-inch stubble were also included in 1925. In the 3 wet years, results were much more favorable than is usually possible. Cutting with the 6-inch to 8-inch stubble showed no advantage to offset the loss in hay yields. The best time to cut was apparently when the growth reached 24 to 30 inches and before the leaves began to fall. In 1927 and 1928 the last cutting was of inferior quality, the plants

FIGURE 24.—Sweetclover of the second-year's growth being cut for hay.

having become more stemmy but less leafy since the preceding cutting. If cut at the right time, first-year sweetclover hay is fine and leafy and similar to alfalfa in value.

The plants generally survived cutting for hay or clipping for weed control at almost any stage during the first year, provided plenty of soil moisture was present. Otherwise, cutting or clipping at any time was attended with much risk. The effects of mowing new seedings of sweetclover in order to kill pigweeds have been noted in several seasons. In 1914 the plots were mowed closely when a thick stand of pigweeds was about half grown. The weeds sent out side branches and soon made a vigorous spreading growth, which was mowed again with difficulty. With dry weather following, the sweetclover did not survive such treatment. In 1915 the weeds were allowed to get more mature, and were mowed closely twice, on June 20 and July 28. In this very wet season the sweetclover survived. In 1916 the weeds were mowed closely on July 1 when 2 feet tall, and the sweetclover, with reserve subsoil moisture, survived the dry fall. The principle followed in recent years with respect to clipping weeds from young

sweetclover, and alfalfa as well, is to wait until the weeds are far enough along so they do not recover quickly and to mow high enough to leave a 6-inch or 8-inch stubble.

### SECOND-YEAR CUTTING

Hay yields from the second-year growth of sweetclover were recorded for the 12 years in which such a cutting was possible (table 28). All yields were obtained from plots seeded in the spring of the previous year, unless otherwise noted (fig. 24). These cuttings were all mowed closely to the ground, except in 1920 and 1921, when a 10-inch to 12-inch stubble was left. Many of the cuttings were delayed by wet weather until too late for a good quality of hay.

TABLE 28.—*Yields of hay obtained from sweetclover in its second year of growth, 1914–28*

| Year | Hay yields per acre | Date cut | Height when cut | Degree or percentage of survival | Remarks |
|---|---|---|---|---|---|
| | *Tons* | | *Inches* | | |
| 1914 | 1.13 | June 12 | | | |
| 1915 | 2.40 | June 20 | 48 to 60 | | Data from 24-inch rows. |
| 1916 | 2.62 | May 26, July 1 | 18 to 30 | None | |
| 1917 | .87 | June 11 | 24 to 30 | Thin | |
| 1918 | 1.24 | June 10 | | None | Seeded Aug. 8, 1917. |
| 1919 | | | | | Stands failed in preceding year. |
| 1920 | 1.46 | May 31 | 30 to 36 | None | From volunteer plot. |
| 1921 | .90 | June 11 | 30 to 40 | Thin | Seeded Aug. 8, 1920. |
| 1922 | 1.93 | May 31 | 42 | Trace | |
| 1923 | | | | | Stands failed in preceding year. |
| 1924 | | | | | Do. |
| 1925 | .98 | June 15 | 20 to 28 | Thin | |
| 1926 | 1.34 | May 25, June 2, June 9 | 24 to 44 | 20 to 60 | |
| 1927 | 1.37 | May 23 | 24 to 30 | 75 to 90 | |
| 1928 | 2.22 | July 3 | 60 | None | Very woody, in full blooms. |
| Average | 1.54 | | | | |

In 1926 and 1927 a direct comparison was made between high and low cutting at different stages of growth (tables 29 and 30). The intention with the higher stubble was to leave several side branches near the base ready to continue growth, since sweetclover does not renew growth directly from the crown like alfalfa. While the estimated percentage of survival was higher from this method, it was gained at too much sacrifice in tonnage of the first cutting. There is apparently no need of leaving a high stubble if the hay crop is taken off at the proper time; that is, when the plants are 24 to 30 inches tall.

In general, second-year sweetclover was rarely attractive as a hay crop. If cut early, before it reached a height of 24 to 30 inches, the plants were leafy and only slightly coarser than alfalfa. But if cutting was delayed by bad weather, as often happened, the plants soon became very coarse and woody.

Survival after the first cutting was very uncertain. In 1916, a year of very favorable weather, two cuttings were obtained, each almost equal to alfalfa in quality. In other seasons the second growth was short, sparsely leafed, and came into bloom so quickly that there was no opportunity for a second cutting of hay.

TABLE 29.—*Yields and survival of sweetclover in its first year when cut for hay at different stages of growth, leaving low and high stubble* [1]

| Year and date | Height of plants | Cutting low | | Cutting at a height of 6 to 8 inches | |
|---|---|---|---|---|---|
| | | Yield per acre | Estimated survival | Yield per acre | Estimated survival |
| 1925: | *Inches* | *Tons* | *Percent* | *Tons* | *Percent* |
| July 10 | 15 to 24 | | 100 | | 100 |
| Aug. 17 | 20 to 32 | 1.38 | 100 | 1.19 | 100 |
| Aug. 31 | 20 to 36 | 1.47 | 100 | 1.29 | 100 |
| Sept. 19 | 20 to 36 | 1.64 | 100 | 1.30 | 100 |
| 1927: | | | | | |
| June 27 | 18 | .80 | 75 | | |
| Sept. 20 | 24 to 30 | 1.55 | 50 | | |
| Oct. 21 | 24 to 30 | 1.16 | 30 | | |
| 1928: | | | | | |
| Aug. 11 | 24 to 30 | 1.33 | | | |
| Aug. 25 | 30 to 34 | 1.77 | | | |

[1] Data are for favorable years, when there was sufficient growth to warrant cutting. These tests extended from 1913 to 1928 and in all but these 3 years (1925, 1927, 1928) no cutting was possible except as explained in the preceding text. The lack of a cutting the first year was due in many cases to failure to obtain a stand.

TABLE 30.—*Yields and survival of sweetclover in its second year when cut for hay at different stages of growth, leaving low and high stubble*

| Year and date | Height of plants | Stage of growth | Cutting low | | Cutting high | | |
|---|---|---|---|---|---|---|---|
| | | | Yield per acre | Estimated survival | Height of stubble | Yield per acre | Estimated survival |
| 1926: | *Inches* | | *Tons* | *Percent* | *Inches* | *Tons* | *Percent* |
| May 10 | 6 to 12 | Very young | 0.09 | 100 | | | |
| May 17 | 12 to 20 | Medium young | .58 | 100 | | | |
| May 25 | 24 to 32 | Best hay | 1.35 | 60 | 6 to 8 | 0.78 | 75 |
| June 2 | 30 to 36 | Getting stemmy | 1.39 | 40 | 8 to 10 | .77 | 50 |
| June 9 | 36 to 44 | First bloom | 1.29 | 20 | 10 to 12 | .71 | 30 |
| June 17 | 36 to 44 | Three fourths bloom | 1.69 | 10 | 12 to 14 | 1.11 | 20 |
| 1927: | | | | | | | |
| May 12 | 18 to 20 | Very young | .79 | 100 | 6 | .43 | 100 |
| May 23 | 24 to 30 | Best hay | 1.37 | 75 | 6 to 8 | 1.03 | 90 |
| June 27 | 48 to 54 | Full bloom | 1.94 | 0 | 12 | 1.41 | 0 |

### SWEETCLOVER AS A PASTURE CROP

The carrying capacity of sweetclover pasture has been determined on a few small general fields of the Hays station.

In 1925 a gently rolling upland field of 8.2 acres in second-year sweetclover was grazed by milk cows. Heavy grazing began on April 18 when the clover was 10 to 20 inches tall. Four calves had grazed here for 10 days up to this time and are counted equivalent to 2 cows. The full herd of 16 cows, 1 bull, and 4 calves grazed continuously on this field from April 20 to May 16, except for 2 wet days. During this time the sweetclover was completely eaten down and required a rest. The herd again grazed intermittently about half the time from May 22 to June 18, also for a few days in July.

The data from this test have been reduced to a unit-day basis per acre, a unit day being the equivalent of 1 cow grazing 1 day. In April grazing amounted to 29 unit days per acre; in May, 45; in June, 21; and in July, 12; a total of 107 unit days for the season. The pasture was able to carry about 2 cows per acre during the best three fourths of the grazing period and 1 cow during the poorest quarter.

This was in a relatively dry spring, and it seems probable that these results are somewhat below the normal possibilities. Considering that the grazing just described was the only return from the land occupied by sweetclover for 2 years, it does not appear a profitable way to use land that could be growing other staple crops. However, it is a matter of common information that sweetclover can generally be used to better advantage for grazing than for hay production and also that it can be grown on much land too thin. rolling, or sandy for other crops.

### NURSERY EXPERIMENTS

Between 1913 and 1928 nursery trials were made of 56 lots of sweetclover collected by the United States Department of Agriculture in different parts of the world and representing most of the strains, types, or varieties of this plant known to be of agricultural value. Part of the material had been in the possession of the Department for several years, and some of it was grown at Hays as early as 1913. A few lots were grown at Hays during 1921 to 1925, but it was not until 1926 that a comprehensive study of the material was begun. Notes until 1930 were available to the writer, hence the observations which follow are based upon 5-years' experience with these varieties.

During the period 1913–28, 59 different lots of sweetclover were under test at Hays. A complete list of these may be found in the annual reports on file in the Division of Forage Crops and Diseases. Not all of these were distinct varieties, but the collection represented practically all the strains and varieties obtainable.

While considerable data in the form of notes on these nursery rows are now available, it appears that the subject of sweetclover varieties and strains has as yet been inadequately studied at Hays. The possibilities in growing sweetclover in the territory served by the Fort Hays station vary rather directly with the amount of rainfall, but there is some evidence that sweetclover will be of value as a soil-building and pasture crop wherever there is cultivated rolling land being impoverished by erosion.

The sweetclovers studied may be classified naturally into biennial white-blossom, biennial yellow-blossom, annual white, and annual yellow types. Of these, the common biennial white (*M. alba*) is the standard variety now being grown in Kansas. This was always grown as a check in the experiments. The biennial yellow (*M. officinalis*) also has some commercial importance, but it is generally criticized for lack of vigor and for not carrying its vegetative growth far enough into the second year. Some growers prefer it for adverse conditions or on account of its finer stems. The annual forms are of only passing interest. Hubam, an annual white, was grown from 1921 to 1927. It grew from 30 to 42 inches tall under favorable conditions but was deficient in leafiness. It showed quick maturity and good seed habits, but as a forage crop it appeared decidedly less useful than the first-year growth of the biennial white varieties.

The annual yellow (*M. indica*), grown only in 1913 and 1914, was least valuable of all, getting only a foot or so tall and producing less forage than a very light growth of alfalfa.

The principal interest in sweetclover varieties lies in the wide variations among different lots of the biennial white as compared with the kind commonly grown also among different lots of the biennial yellow, of which the *Melilotus officinalis* commonly grown is probably the least valuable.

Several strains of biennial white are finer stemmed, less vigorous, and 2 to 3 weeks earlier in blooming than the common. This class included F.C. 2427 (Grundy County), 05326 (Crystal Dwarf), and 12067 (Stone's Early), a selection from the Grundy County strain. It is not clear how such lots as these can be as useful under Kansas conditions as the common biennial white, especially for soil building and pasture.

A few strains of biennial white are apparently a little more vigorous, a few days later in blooming, and possibly coarser than the common. Chief among these probably is Chantland's F.C. 05647; next, Parker's F.C. 04883; then S.P.I. 19848, 27463, and 27465. These types should be more carefully studied, and perhaps subjected to several years of selection, with a view to distribution of the most vigorous possible type for soil building and pasture wherever the annual rainfall justifies a large-growing variety.

Among the biennial yellow lots there is one group grown under various botanical names and characterized by late growth in the fall of the first year. This group included S.P.I. 27291, 27474, 27475, 27476, and 27477. The second-year growth of this group was disappointing, the lower two thirds of the plant being coarse and scantily leafed. The blooming season was early, though about 10 days later than for *Melilotus officinalis*. Lots such as these might serve a valuable purpose for growers interested primarily in the production of sweetclover the first season, with the expectation of plowing it out the second spring.

Two lots of biennial yellow were noted for a long period of vegetative growth the second year. These were S.P.I. 40937, selected at the Redfield, S.Dak. station, and 61320 from Siberia. In 1927 S.P.I. 40937 reached full bloom at Hays by July 12, as compared with May 25 to 27 for the *Melilotus officinalis* group, June 6 to 10 for the *M. suaveolens* group, and June 18 for regular biennial white. In 1928 S.P.I. 61320 was also included in this comparison, and full bloom was recorded at the following dates: S.P.I. 61320, July 10, and 40937, July 4; *M. officinalis* group, June 6; *M. suaveolens* group, June 8; common biennial white, June 28; group of largest biennial white strains, July 2 to 6. S.P.I. 61320 is very similar to the common biennial white in size and coarseness, but continues vegetative growth a little longer than any other sweetclover so far noted in its second year. S.P.I. 40937 is just a little smaller, and somewhat earlier. This delayed blooming habit is a favorable quality from the standpoint of pasture, since it is desirable for a pasture to remain in a vegetative stage for the longest time possible. Unfortunately, both S.P.I. 61320 and 40937 are among the poorest lots with respect to vigor and late growth in the fall of the first year; also they seed less freely than earlier-maturing sorts, and therefore the seed would be more expensive. While there is a good deal of interest in these late-blooming, yellow-flowered types, it is a question whether one can afford to use a variety that makes an inferior growth through the first year, takes the maximum time in proportion to its growth the second year, and forms seed at a time when drought is more likely to be acute than if earlier.

Additional selections were added to the sweetclover nursery in 1929 and 1930, some of which are promising and different from anything previously included. Apparently a large field exists for further

survey of existing types and for the selection and testing of superior strains for the different purposes and geographical conditions under which the crop is or may be grown. There appears to be a need for more exhaustive, coordinated work on this project throughout the country, similar to that already done on such forage crops as the sorghums, alfalfa, and annual legumes.

## ANNUAL LEGUMES

The following annual legumes have been tested sufficiently at Hays to supply data: Field peas, cowpeas, soybeans, tepary beans, and pinto beans. Other annual legumes grown on a limited scale were hairy vetch, chickpeas, mung bean, navy bean, Korean lespedeza, and the white and yellow annual sweetclovers. The annual clovers have already been discussed in the section on sweetclover.

Yield data for the first five crops named are presented in table 31. Beginning in 1915, one series of tests was usually conducted within a woven-wire enclosure fenced against rabbits. This precaution was very necessary for the soybeans, sometimes of value to tepary and pinto beans, but rarely, if ever, needed for field peas and cowpeas. The field peas were grown in close drills and the other four crops in 40-inch surface-planted rows.

The yields as a whole were disappointing, indicating that relatively little, if any, profit is to be expected from growing the crops under conditions similar to those at Hays. Even the yields reported here would scarcely be obtained under farm conditions, for these legumes were favored considerably in the experiments. Unusual care was taken in providing a good seed bed, keeping down weeds, and controlling grasshoppers.

Tepary beans ranked highest in the group as a forage crop. The merits of each crop are discussed under separate headings.

TABLE 31.—*Yields of annual legumes, 1913–28*

ACRE YIELDS OF TOTAL CROP (TONS)

| Year | Field peas; open field | Early Buff cowpeas | | Soybeans | | White tepary beans | | Yellow tepary beans | | Pinto beans | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Open field | Fenced | Open field | Fenced | Open field | Fenced | Open field | Fenced | Open field | Fenced |
| 1913 | 0.32 | 0 | | 0 | | | | | | | |
| 1914 | 1.38 | 1.87 | | .54 | | 2.04 | | | | | |
| 1915 | 1.26 | .62 | | .07 | 1.88 | 1.05 | | | | | |
| 1916 | .89 | .47 | 0.72 | 0 | .80 | .85 | 1.17 | | | | |
| 1917 | 0 | .20 | .61 | 0 | .66 | 0 | .43 | | | 0.10 | 0.70 |
| 1918 | .77 | .72 | .45 | 0 | .59 | 0 | .90 | | | .36 | .50 |
| 1919 | | .76 | .61 | 0 | .65 | .79 | 1.13 | | | .40 | 1.05 |
| 1920 | | 1.33 | 1.18 | 1.22 | 0 | 1.66 | 1.96 | 1.74 | 2.09 | 1.09 | 1.43 |
| 1921 | | 1.23 | .95 | 0 | .71 | 1.46 | 1.44 | 1.50 | 1.55 | .60 | .36 |
| 1922 | | .97 | 1.13 | .35 | .18 | .50 | .84 | .70 | .88 | .35 | .44 |
| 1923 | | 0 | .94 | 0 | 0 | 0 | 1.20 | 0 | 1.27 | 0 | .32 |
| 1924 | | 1.30 | | | 1.07 | 0 | | 0 | | 0 | |
| 1925 | | 1.94 | | | 2.40 | | 2.13 | | 2.48 | | .62 |
| 1926 | | .70 | | | 1.09 | | 1.13 | | 1.73 | | .76 |
| 1927 | | .60 | | | 1.49 | | 1.54 | | 1.60 | | |
| 1928 | | 1.36 | | | 1.10 | | 1.83 | | 1.92 | | .46 |
| Average | .77 | .88 | .82 | .20 | .90 | .76 | 1.31 | .79 | 1.69 | .36 | .66 |

TABLE 31.—*Yields of annual legumes, 1913–28*—Continued

ACRE YIELDS OF SEED (BUSHELS)

| Year | Field peas; open field | Early Buff cowpeas | | Soybeans | | White tepary beans | | Yellow tepary beans | | Pinto beans | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Open field | Fenced | Open field | Fenced | Open field | Fenced | Open field | Fenced | Open field | Fenced |
| 1913 | 1.5 | 0 | | 0 | | | | | | | |
| 1914 | 7.0 | 1.1 | | 4.4 | | 2.7 | | | | | |
| 1915 | 4.6 | 1.8 | | 0 | 18.0 | 10.7 | | | | | |
| 1916 | 8.0 | 3.8 | 5.3 | 0 | 9.3 | 0 | 0 | | | | |
| 1917 | 0 | 2.9 | 8.5 | 0 | 4.5 | 0 | 2.2 | | | 0.5 | 6.8 |
| 1918 | 3.0 | 0 | 6.3 | 0 | 0 | 0 | 0 | | | 0 | 0 |
| 1919 | | 4.6 | 5.8 | 0 | 3.3 | 3.8 | 7.0 | | | | 0 |
| 1920 | | 8.7 | 11.3 | 18.0 | 0 | 22.5 | 21.3 | 27.2 | 24.5 | 12.1 | 13.5 |
| 1921 | | 13.9 | 6.8 | 0 | 6.7 | 16.2 | 13.7 | 19.2 | 18.3 | 0 | 0 |
| 1922 | | 4.7 | 12.4 | 0 | 0 | 1.4 | 5.7 | 4.5 | 8.0 | 0 | 0 |
| 1923 | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1924 | | 11.8 | | | 6.9 | 0 | | 0 | | 0 | |
| 1925 | | 23.4 | | | 23.3 | | 18.1 | | 20.7 | | 3.4 |
| 1926 | | 3.8 | | | 9.8 | | 8.1 | | 12.6 | | 0 |
| 1927 | | 7.5 | | | 11.0 | | 13.8 | | 17.2 | | |
| 1928 | | 14.9 | | | 9.1 | | 10.2 | | 9.7 | | 1.5 |
| Average | 4.0 | 6.4 | 7.1 | 2.0 | 7.3 | 5.2 | 8.3 | 10.2 | 13.9 | 1.6 | 2.5 |

### FIELD PEAS

The data for field peas in table 31 were obtained from the variety Hubert, S.P.I. 24893, seeded in close drills at 90 pounds per acre. This was chosen as the best among a list of spring-seeded varieties grown in 1913 and 1914 in duplicate $\frac{1}{20}$-acre plots. Hubert was relatively early with reddish-purple flowers. The other varieties tested in 1913 were White, S.P.I. 3179 and 3182; Speckled, S.P.I. 17006; Blackeye, S.P.I. 22044, and Golden Vine, S.P.I. 30134. Speckled and Blackeye were also grown in 1914, but only Hubert was continued through 1915 to 1918. The seeding dates ranged from March 25 to April 20 and harvest from June 22 to July 7. It seems that seeding should have been completed about April 1 or earlier, as field peas develop best in a cool humid climate and suffer greatly from dry hot weather such as they often encountered at Hays after early June. At best, field peas are poorly adapted to this section, and their culture was discontinued after 1918.

The Hubert was grown from 1915 to 1918 in cultivated 40-inch double rows for comparison with the close-drilled method. These double rows were seeded with an 8-inch drill, using two adjacent holes and stopping up the next three. The drill remained set at the same rate throughout both methods, thus putting on two fifths as much seed per acre on the double row plots as with the close drills. Both methods were total failures in 1917, and there was little difference between methods for the other seasons. The 4-year average yields per acre were as follows: Close drills, 0.73 ton hay and 3.5 bushels grain; 40-inch double rows, 0.56 ton hay and 4.0 bushels grain.

### FALL-SEEDED FIELD PEAS

Fall seeding has been tried with several varieties of field peas, usually during the latter part of September. The Austrian Winter peas, obtained from Austria in 1911, proved 50 to 90 percent winter-hardy during the five winters following, but killed out during 1916–17, and only a few scattering plants survived in 1917–18, after which tests

of it were discontinued. The Austrian Winter proved similar to the spring-seeded variety, Hubert, in character of foliage, color of flowers, amount of growth, and date of maturity. Other field peas seeded in the fall were as follows:

October 8, 1913, Kaiser, S.P.I. 17006, Kovaleff, S.P.I. 20382, Grey Winter, S.P.I. 16436, Golden Vine, S.P.I. 34941.
September 26, 1914, Erfurt, S.P.I. 18606, Blue Imperial, S.P.I. 29367.
September 26, 1917, Solo, F.C. 1703, Partridge, S.P.I. 16437-A, Peluschka, S.P.I. 22079, Fraile, S.P.I. 24314, Golden Vine, S.P.I. 34941.

The only winter survival among these seedings for the three seasons consisted of a few scattered plants of S.P.I. 16436 in 1914. This variety is the same as the Austrian Winter pea.

### COWPEAS

Cowpeas have received more attention than any other class of annual legumes in the experiments at Hays. One variety, Early Buff, was carried continuously in plot tests from 1914 to 1928 (fig. 25). The Groit and Blackeye varieties were also grown in plot tests,

FIGURE 25.—Early Buff cowpeas in cultivated rows. This variety was the most consistent seed producer but made light forage yields.

the former in 1914 and 1915 and the latter from 1920 to 1923. Work with numerous varieties in smaller plots of 0.01 to 0.02 acre were usually but not always duplicated.

In 1916 forage yields in tons per acre were reported from 10 varieties as follows: Brabham, 0.84; Catjang, 0.48; Early Buff, 0.72; Early Red, 0.80; Groit, 1.12; Iron, 0.52; Monetta, 0.68; New Era, 0.96; Taylor, 0.76, and Whippoorwill, 0.88. The only seed yields produced by these varieties were from Catjang, 2.7 bushels, and Early Buff, 5.3 bushels per acre.

In 1917, 12 selections, mostly Blackeye, were under observation in 22-foot rows in the nursery. This test indicated and afterward proved that the Blackeye group contains some of the best cowpeas for this section.

Blackeye cowpeas that had descended from the 1917 selections were grown in regular plot tests in comparison with Early Buff for

4 years, 1920 to 1923. The average yields per acre for eight tests were as follows: Blackeye, 0.96 ton of dry forage; Early Buff, 0.97 ton; Blackeye, 6.7 bushels of seed; Early Buff, 7.2 bushels.

A collection of cowpea varieties received by the agronomy department, Kansas State College of Agriculture and Applied Science, Manhattan, Kans., from the Arkansas Agricultural Experiment Station in the spring of 1924 was grown at Hays for the period 1924–28, inclusive. Data obtained from these tests are shown in table 32, mainly in averages. There appeared to be too much experimental error involved in results from plots of only 0.01 or 0.02 acre to warrant presenting the results separately for each season, but it is believed that the averages give a reliable index to the relative merits of the varieties.

TABLE 32.—*Results from tests of cowpea varieties, 1924–28*

| Variety | Kansas cooperative experiment no.[1] | Habit [2] | Season (average days to maturity) | Seeds per pound, 1927 | Average yields per acre | | Value [4] |
|---|---|---|---|---|---|---|---|
| | | | | | Total crop | Seed [3] | |
| | | | *Days* | *Number* | *Tons* | *Bushels* | |
| Arlington | 1001 | S-E | 101 | 3,900 | 1.49 | 9.6 | A |
| Blue Goose | 1003 | S-E | 101 | 4,000 | 1.02 | 4.4 | C |
| Black Unknown | 1015 | S-E | 106 | 2,960 | 1.27 | 2.4 | C |
| Blackeye group: | | | | | | | |
| California Blackeye | 945 | S | 88 | 2,570 | 1.17 | 10.4 | A |
| Extra Early Blackeye | 1021 | S | 94 | 2,510 | 1.24 | 9.6 | A |
| Gallavant | 1010 | S | 87 | 2,500 | 1.03 | 9.4 | A |
| Forty-Day Blackeye | 946 | MS | 92 | 2,430 | 1.20 | 12.5 | A |
| Blackeye (Local) | ------- | S | 91 | 2,570 | 1.20 | 12.1 | A |
| Brabham [5] | 1000 | E | 111 | ------- | 1.04 | .3 | C |
| Catjang | 1016 | E | 93 | 6,220 | .93 | 4.1 | C |
| Clay [6] | 1025 | VS | 107 | ------- | 1.25 | .1 | C |
| Columbia | 1020 | S-E | 101 | 3,480 | .94 | 2.5 | C |
| Cream | 1002 | S | 98 | 3,750 | 1.05 | 6.7 | B |
| Crowder group: | | | | | | | |
| Sugar Crowder | 1018 | VS | 107 | 2,870 | 1.14 | 1.3 | C |
| White Sugar Crowder | 1005 | S | 102 | 2,870 | 1.25 | 6.4 | B |
| Brown Crowder | 1014 | S-E | 107 | 2,740 | 1.16 | 2.9 | C |
| Large Brown Sugar Crowder | 1007 | VS | 108 | 2,100 | 1.13 | 2.4 | C |
| Early Buff | 1006 | S-E | 85 | 2,530 | 1.18 | 12.3 | A |
| Early Red | 997 | S-E | 103 | 3,300 | 1.23 | 4.9 | B |
| Extra Early Black | 1004 | S-E | 102 | 2,560 | 1.41 | 7.2 | A |
| Groit | 998 | S-E | 105 | 3,150 | 1.36 | 5.0 | B |
| Holstein | 1022 | S | 102 | 2,550 | 1.43 | 7.6 | A |
| Iron | 1024 | S-E | 104 | 3,640 | 1.29 | 2.2 | C |
| Monetta | 1011 | E | 105 | 3,320 | 1.21 | 1.5 | C |
| New Era | 943 | S-E | 101 | 3,710 | 1.04 | 4.2 | C |
| New Era×Blackeye | 1017 | S-E | 101 | 2,790 | 1.36 | 5.8 | A |
| Oliver's Hybrid | 1013 | S | 102 | 3,120 | 1.29 | 6.1 | A |
| Oliver's White | 999 | S | 92 | 2,590 | 1.02 | 9.4 | A |
| Peerless | 1019 | S-E | 104 | 3,770 | 1.41 | 4.1 | B |
| Red Ripper | 1023 | MS | 102 | 2,730 | 1.21 | 5.0 | B |
| Two-Crop | 1012 | S-E | 102 | 2,960 | 1.33 | 5.4 | B |
| Warren's New Hybrid | 1008 | S-E | 101 | 3,090 | 1.33 | 5.3 | B |
| Whippoorwill | 944 | S-E | 105 | 3,020 | 1.38 | 3.8 | B |
| White Hybrid | 1009 | S-E | 94 | 4,040 | 1.27 | 8.5 | A |

[1] These numbers were assigned by the cooperative experiment section of the agronomy department, Kansas State College of Agriculture and Applied Science, Manhattan, Kans., in the spring of 1924, on receipt of the seed from the Arkansas Agricultural Experiment Station.

[2] E=Erect; M=medium; V=very; S=spreading.

[3] Seed=60 pounds per bushel.

[4] A=Best group, usually early varieties of good seed habits; Arlington was the best forage type in this class. B=Medium value and not of interest at Hays. C=Least attractive, often because of fault in the plant itself, such as very light scanty foliage in Catjang; coarse prostrate vines in Crowders.

[5] Three years, 1924–26.

[6] Two years, 1924 and 1925.

The varieties marked A in the last column of table 32 are considered to have made the best showing. Arlington was one of the better varieties for forage and also had fair seed habits. It was difficult to find satisfactory forage and seed production combined, as will be noted from the yields of other varieties in the A group. Varieties early enough to mature dependable and relatively high yields of seed usually are light in vegetative habits, as in Early Buff and Blackeye. Varieties such as Brabham, Groit, New Era, and Whippoorwill, that are standard in certain more humid sections, seem unable to develop fully at Hays. It is quite common for drought to make itself felt severely in these tests just about the time the earliest varieties have matured; the rest then dry up rapidly and somewhat prematurely, shedding their leaves if not harvested promptly.

The best average yields of forage and seed in this 5-year cowpea test are only about half the yield that should be produced in a section in which they are adapted. These 5 years were also relatively favorable, and the varieties were given more than average care. In view of the more satisfactory results readily obtained from other forage crops at Hays, it does not appear that the growing of cowpeas on a commercial scale in this section is justified.

### SOYBEANS

The soybean tests in 1913 all failed entirely. They consisted of single-row tests of F.C. 6928, 6929, and 6930; S.P.I. 18227, 20854, 30745, 30746, and 30747. In 1914 open-field plot tests of one twentieth to one tenth of an acre were grown of three varieties, with yields per acre as follows: Green, S.P.I. 28050, 1.19 tons of forage, 10 bushels of grain; Black Eyebrow, S.P.I. 30744, 0.44 ton of forage, 3.3 bushels of grain; Tashing, S.P.I. 20854, seeded 13 days later, was destroyed by rabbits. The average of these three seedings was used in table 31 for the 1914 results with soybeans.

In 1915 S.P.I. 28050 and 30744 were seeded again in duplicate $\frac{1}{10}$-acre plots under open-field conditions, but rabbits left only a few stubs of plants. Ten S.P.I. numbers grown in 1915 in single 10-rod rows under fence did much better. The numbers grown, together with their lengths of season and their yields, are shown in table 33.

TABLE 33.—*Results with 10 S.P.I. numbers of soybeans, 1915*

| S.P.I. no. | Season (days to maturity) | Acre yields | | S.P.I. no. | Season (days to maturity) | Acre yields | |
|---|---|---|---|---|---|---|---|
| | | Forage | Grain | | | Forage | Grain |
| | *Days* | *Tons* | *Bushels* | | *Days* | *Tons* | *Bushels* |
| 30593 (Manchu) | 99 | 1.44 | 18.0 | 30744 (Black Eyebrow) | 100 | .92 | 11.3 |
| 30594 | 94 | .84 | 9.3 | 36647 | 110 | .80 | 10.0 |
| 30599 | 106 | 1.72 | 22.0 | 36648 | 114 | 1.88 | 18.0 |
| 30600 (Wea) | 106 | 1.20 | 16.0 | 36917 | 105 | .92 | 9.3 |
| 30601 | 100 | 1.68 | 20.0 | 37062 | 110 | .80 | 10.0 |

The results in table 33 are of interest for showing practically the maximum possibilities of soybeans at Hays. The 20-day range in maturity and the wide fluctuations in yield illustrate the marked differences that exist even among early and medium-early varieties. S.P.I. 30599, 30601, and 36648 were continued into plot tests in

1916, with yields per acre, respectively, as follows: Forage 0.41, 0.28, and 0.80 ton; grain 5, 3, and 9.3 bushels. On the basis of the 1915–16 results, S.P.I. 36648 alone was continued in the plot tests, and the data presented for 1915 to 1923 in table 31 were from this variety.

In 1924 a new test of 16 soybean varieties was begun in 1-row or 2-row plots within a rabbit-proof enclosure. Several varieties were discarded within the first year or two, but 10 were grown for the full 5-year period, 1924–28, with average results as shown in table 34. This was a favorable series of seasons, and the soybeans received special care as to the control of weeds, grasshoppers, and blister beetles. The results, therefore, approach the maximum rather than the normal possibilities of soybeans for this locality. A.K. was considered the best, and its performance was used in completing the last 5 years of the soybean data in table 31.

TABLE 34.—*Results with soybean varieties, 1924–28*

| Variety | Kansas cooperative experiment no. | Season (days to maturity) [1] | Average height | Average acre yields | | Relative value [3] |
|---|---|---|---|---|---|---|
| | | | | Total crop | Seed [2] | |
| | | | *Inches* | *Tons* | *Bushels* | |
| A.K. | 929 | 117 | 28 | 1.43 | 12.0 | A |
| Arlington | | 121 | 33 | 1.31 | 9.8 | B |
| Haberlandt | | 111 | 22 | .97 | 9.2 | B |
| Lucas | 935 | 117 | 25 | 1.36 | 11.3 | A |
| Manchu | 936 | 111 | 23 | 1.02 | 9.9 | B |
| Morse | 931 | 119 | 29 | 1.15 | 7.8 | B |
| Peking | | 121 | 25 | 1.08 | 7.7 | C |
| Sable | 934 | 121 | 26 | 1.10 | 7.1 | C |
| Virginia | 932 | 120 | 33 | .95 | 7.1 | C |
| Wilson | 930 | 116 | 31 | 1.01 | 7.4 | C |

[1] 1925 to 1928.
[2] Bushel=60 pounds.
[3] A=Best all-around varieties for both forage and grain; B=medium value; C=least promising.

The 16 varieties were grouped as follows as to practical value:

*Best.*—Well balanced as to vegetative and seed habits; good type of yellow seed—A.K., Lucas, Morse, Manchu, and Haberlandt. The latter two were noted for early maturity, but had lighter foliage than was desired. Morse was similar to A. K., except a little later and not so well filled.

*Satisfactory.*—Good vigor in most cases, but showing some objectionable feature, such as poor seed yields, wrong type of seed, or late maturity. This group contained the following:

(1) Tall vigorous types with only mediocre foliage and seed habits—Arlington, Wilson, and Virginia.

(2) Miscellaneous—Peking, small black beans; Sable, small black seeds and too late; Midwest and Chiquita, too late.

*Poorest.*—This group was discarded after one season's test, 1924, for lack of vigor and for scarcity of pods except in the lowest 6 or 8 inches of stem—Austin, Black Eyebrow, Lexington, and Wea.

The lengths of season shown for soybean varieties for 1924 to 1928 are comparable with those given for the tepary beans, but not with those of cowpeas. The reason for this is that the cowpeas had to be replanted in 2 years, while other legumes did not; the later the seeding the shorter the season required for maturity. The soybeans were seeded within the period from May 17 to May 29. While they are a warm-weather crop, they stand more cold than cowpeas, almost in the same proportion of corn to the sorghums. The soybeans could have been started 10 days or more earlier than was done in these tests,

although it seemed desirable to seed later in order to have time to take care of the weed growth. The advantage gained by soybeans over cowpeas by their resistance to cold wet soil was offset by the distinct superiority of the latter in pushing up through a hard crust.

Inoculation of soybeans has been considered unnecessary at Hays, since the crop grows very well when ideal conditions of moisture and protection are furnished. The only trial made on this subject was with Lucas soybeans in 1924, when Nitragin was used, and no apparent difference was noted between the crop from inoculated and that from noninoculated seed.

Soybeans are relatively coarse stemmed, and most of the leaves generally fall quickly in advance of the ripening of the grain. These factors limit the usefulness of soybeans as a hay crop. In the experiments, it was customary to determine the hay yields from one half of the plot and the grain yields later from the other half.

The main object in growing soybeans in this region would be for the grain which could be pastured off by hogs or sheep. However, the grain yields at Hays, even for the favorable period, 1924–28, are only one third to one half those reported for more humid sections of the United States. While soybeans can be grown to some extent anywhere in Kansas, the area of their profitable use in the State, according to the Kansas State College of Agriculture and Applied Science, is limited to the three eastern tiers of counties.

Rabbits are a decidedly limiting factor in soybean culture in the dry-land sections and often clean off exposed plantings before the plants are 6 inches tall. If soybeans were grown on a large-field scale, however, this factor would be minimized just as in the case of bird injury to grain sorghums. Because of such factors as soil depletion, alfalfa failure, the demand for something better than oats and barley as cash crops in the rotation, education in methods of livestock management, and the probable improvement in soybean varieties, it seems possible that farmers will gradually look with increasing favor on soybeans, and extend the area of their profitable use somewhat farther west than the three tiers of counties previously mentioned.

### TEPARY BEANS

The tepary bean is outstanding in yield and quality of forage among the annual legumes tested. The stems are as fine or finer than alfalfa, and the leaves are abundant, thin, and scarcely one fourth the size of a cowpea leaf. The leaves are generally well retained until the seed is mature, and neither leaves nor seed pods shatter seriously. The vines spread freely to meet adjoining 40-inch rows, and they intertwine with adjacent plants in the same row (fig. 26). The plants grow only 1 to 1½ feet tall, and they spread out so much on the ground that apparently the only method of machine harvesting is with knives running under the surface soil. This is more feasible in sandy than in loam or clay soils.

The seed yields of tepary beans are also relatively high among the annual legumes at Hays. White is the commonest color, and the white tepary beans resemble navy beans very much in size and appearance. Yellow tepary beans have similar seed to that of the white except for the color. The limiting factor in the use of tepary beans as food for man is that they have a noticeable bitterness of flavor, otherwise they can be used the same as navy beans.

While tepary beans have no economic importance in Kansas at the present time, it appears that they could be used as a hogging-off crop, and might be harvested as a hay and seed crop, especially on lighter soils in the southwestern part of the State. The tepary bean is already grown to some extent in New Mexico and Arizona. While the plots in exposed locations were destroyed by rabbits in 1917, 1918, and 1924, these beans are not nearly so attractive to rabbits as soybeans, and in commercial fields they would likely escape serious rabbit injury.

Two strains of the white tepary beans have been grown at Hays. One of these, grown from 1914 to 1928, is later by about 10 days, and in some seasons it has barely matured at Hays. It is the one from which the data were obtained for the general comparison of legumes in table 31. An earlier strain, which was found adapted to conditions at Redfield, S.Dak., was tried at Hays from 1926 to 1928. It is rela-

FIGURE 26.—Tepary beans, one of the most promising legumes for this section of the United States.

tively light in vegetative growth, but a prolific seed producer. The average results for three strains of tepary beans at Hays for 1926 to 1928 are shown in table 35.

TABLE 35.—*Results with three strains of tepary beans, 1926–28, inclusive*

| Strain | Average season | Average acre yield | |
|---|---|---|---|
| | | Forage (including seed) | Seed [1] |
| | *Days* | *Tons* | *Bushels* |
| White [2] | 118 | 1.50 | 10.7 |
| White [3] | 110 | 1.54 | 17.6 |
| Yellow | 116 | 1.75 | 13.2 |

[1] Bushel=60 pounds.
[2] Local strain.
[3] Adapted to conditions at Redfield, S.Dak.

### PINTO BEANS

Pinto beans can scarcely be considered as a forage crop, since their vegetative growth is light and their principal usage is food for man. They were taken on as a phase of the Hays forage-crop project in 1917 because of local interest. No one knew definitely how these beans could be expected to yield or what problems would have to be met in their culture. An unusually large abandonment of winter-wheat acreage that spring, and the war-time demand for food production together furnished the setting for the interest in growing the crop. The beans were not very widely planted, however, and because the season of 1917 was very dry in July, the crop was not good enough to encourage much further interest, except for limited use in gardens.

The data in table 31 on general comparisons of annual legumes at Hays show that pinto beans were grown from 1917 to 1928 and were the poorest legume on the list. While they have been observed growing extensively and standing considerable drought in cooler, higher sections of the Plains in northeastern Colorado, pinto beans set very poorly under the more severe extremes of heat usually associated with dry seasons at Hays.

In addition to the comparison with other legumes, pinto beans were also grown in a number of cultural-method experiments at Hays from 1917 to 1920, and the results are presented in table 36. The seedings were made in surface-planted 40-inch rows except where a different method is indicated. The crops of 1917 and 1919 were very poor, and that of 1918 was an entire failure. In 1920, with a wet fall, results were fair, but, as in the preceding years, they did not show any one method to be superior. As popular interest in the crop no longer existed, the experiments were discontinued.

TABLE 36.—*Results with pinto beans grown under various cultural methods, 1917–20, inclusive* [1]

| Cultural methods | Seed yields per acre (bushels)[2] | | | |
|---|---|---|---|---|
| | 1917 | 1919 | 1920 | Average |
| Date of seeding: | | | | |
| Early, Apr. 30 to May 18 | 3.5 | 0 | 15.4 | 6.3 |
| Late, June 1 to 12 | 4.3 | 0 | 12.1 | 5.5 |
| Spacing in the rows: | | | | |
| Thick, 6-inch row space | 3.3 | 3.1 | (3) | 3.2 |
| Medium, 12-inch row space | 3.5 | 3.4 | (3) | 3.5 |
| Thin, 18-inch row space | 3.5 | 2.8 | (3) | 3.2 |
| Space between rows: | | | | |
| Narrow, 21 to 24 inches | 4.4 | 0 | 11.9 | 5.4 |
| Medium, 40 inches | 4.1 | 0 | 12.1 | 5.4 |
| Wide, 56 to 63 inches | 4.6 | 0 | 8.6 | 4.4 |
| Surface planting compared with listing: | | | | |
| Surface planting | 4.1 | 0 | 12.1 | 5.4 |
| Listing | 3.5 | 6.2 | 12.9 | 7.5 |

[1] Figures for 1918 are omitted because of the complete failure of all methods during that year.
[2] Bushel=60 pounds.
[3] Not conducted in 1920.

### HAIRY VETCH

Seedings of hairy vetch were made in close-drilled plots at winter-wheat seeding time for 5 consecutive years. S.P.I. 24934, seeded October 8, 1913, came up to a fair stand, but winterkilled. D.L. 30, seeded September 26, 1914, survived well and made a vigorous

growth which was 2 feet tall and beginning to bloom by May 26, 1915. It lodged badly during the wet June of 1915, and the hay crop of 1.16 tons per acre was harvested with much difficulty.

On a neighboring farm a 5-acre field, formerly poor wheat land, was drilled on August 30, 1914, to a mixture of about 10 pounds of rye and 40 pounds of vetch per acre. On June 15, 1915, there was a heavy growth, the rye being 4 to 5 feet tall and supporting vetch 2 to 3 feet tall. Back from the edge of the field, however, the vetch did not do very well, as the rye was too thick for it. The two experiences of 1915 show the desirability of having the vetch supported, but the moisture supply in most years is not sufficient for the vetch to withstand rye competition.

Hairy vetch was not grown on the forage-crop project proper in 1916, but a strip of about ¼ acre on an adjoining field was observed. It came through the winter to just a fair stand and was scarcely a foot tall on May 26, 1916. Austrian Winter field peas beside the vetch were more than twice as rank. Hairy vetch was seeded in comparison with field peas on September 13, 1916, and on September 26, 1917. The only winter survival of vetch consisted of a few plants from the latter seeding. No further attempts were made at growing hairy vetch, as it did not appear hardy enough to justify attention in this section. The vetch in these experiments had more than an average opportunity, for it was usually seeded on summer-fallowed land.

#### CHICKPEAS

The growing of chickpeas was attempted at Hays in single-row tests in 1913, 1914, and 1924 with very poor results. In 1913 a seeding of 17 S.P.I. numbers was made on May 14. Germination was irregular, and early growth was slow; the best selections were only 8 to 10 inches tall on July 4, after which grasshoppers destroyed them. A $\frac{1}{10}$-acre plot seeded in 40-inch rows on May 28, 1914, germinated poorly and was discarded. Nursery rows of S.P.I. 24564 and 27513 seeded May 11, 1914, grew only a foot high, were very scantily leafed, and were only fair in seed habits. Single rows of S.P.I. 58038 and 58086 were seeded May 22, 1924, and replanted on June 9. They came up poorly, grew very slowly for a few weeks, and disappeared about July 1, owing to attacks of grasshoppers, blister beetles, and rabbits.

It may be that these experiments were not put in early enough for best results, as this crop, like the field pea, is said to need a cool season of growth. At best, however, the chickpea is not considered a good forage crop because its foliage is too light and it is unpalatable because of an acid secretion. The crop is said to be grown in winter in Mexico and to a limited extent in California, mainly as food for man. It apparently has no place under Kansas conditions.

#### MUNG BEANS

Mung beans received from an Atlanta, Ga., seed house were grown in a $\frac{1}{20}$-acre plot in 40-inch rows at Hays in 1921. They were seeded May 27, under fence and under comparable conditions with the other annual legume plots of that season. The mung beans made a very poor growth, 0.56 ton per acre, and failed in seed production. Their poor showing discouraged any further tests, especially as there is apparently no interest in mung beans in this territory. The crop is said to be similar in adaptation to the cowpea.

#### NAVY BEANS

Navy beans are almost wholly a crop for human consumption, but they are mentioned here because a plot of them was seeded May 27, 1921, under fence with the mung beans and other legumes. They produced very poor growth, yielding 0.16-ton forage and 1 bushel of seed per acre. Tepary beans in the same test averaged 1½ tons forage yield and 16 bushels of seed. Navy beans require cooler humid conditions.

#### KOREAN LESPEDEZA

Korean lespedeza has recently attracted favorable attention in the eastern United States for its pasture possibilities, as it matures farther north than Japanese lespedeza and produces seed freely. It was grown at Hays from 1923–28 in square-rod plots or in nursery rows, and in 1924 it was broadcast in a number of places such as in waste land around buildings, draws in native pasture, and on well-prepared farm land. Stands were readily obtained from March to May under the very favorable conditions of the nursery, usually on fallowed land, but other seedings failed. The plants in the nursery regularly grew 6 to 8 inches tall and set seed freely. Volunteer stands also came on readily after the first year. Korean lespedeza does not appear to have any considerable value in this territory as a forage crop.

### OTHER LEGUMES

#### KUDZU

Six plants of kudzu were established at Hays in April 1927 by transplanting roots received from the agronomy department, Kansas State College of Agriculture and Applied Science. This perennial legume has been reported as producing a heavy growth of excellent forage when fully established at Manhattan. The crop has attained some popularity in Florida, and apparently would have a wider usefulness for hay, pasture, and ornamental purposes if it were not necessary to start it from roots and to wait until the third year for full production. The plants at Hays were located along a 5-foot woven wire fence with 20 feet of fallow ground on one side, and they also enjoyed very wet seasons in 1927 and 1928. In 1927 they sent out very scantily leafed runners to a length of 10 to 15 feet. The roots survived the winter of 1927–28 and produced much more abundant foliage in 1928 when the fence was well covered and vines again spread 10 or more feet. No blooming was noted in either season. It is not anticipated that kudzu will ever be of much value as a forage crop at Hays, but it may prove of some interest for growing in favored locations for ornamental purposes.

#### SAINFOIN

Sainfoin is a perennial legume that has long been of value in France and some other European countries for growing on calcareous soils subject to drought. It has been widely tested in the United States but has assumed no economic importance. On May 14, 1913, sainfoin was seeded at Hays in rows 36 inches apart. A poor stand resulted and the plants did not survive the severe season, whereas alfalfa and sweetclover seeded under comparable soil conditions survived. Another seeding of sainfoin was made in 42-inch rows on May 7, 1914. With a favorable season, three cultivations, and some hand weeding,

it grew 6 to 8 inches tall, which was much less than the growth of alfalfa or sweetclover under these conditions. The sainfoin evidently did not suffer through lack of inoculation, for nodules were found on the roots of a plant dug up on October 2, 1914. It was carried over to 1915, but rabbits ate it off repeatedly when it was 3 or 4 inches high, and by midsummer the plants apparently were killed by them. Two rows seeded in 1914, within a fenced nursery, practically escaped rabbit injury in 1915. The plants began to bloom May 26 and were cut on July 7, when 1 to 2 feet tall, with some flowers still appearing and with some mature seed pods. By September 9 they had made 8 to 12 inches of second growth. In this favorable year alfalfa made approximately three times the yield of sainfoin, and tests of the latter were discontinued.

#### TEDERA

A rod row of tedera (*Psoralea bituminosa*), S.P.I. 65033, was seeded at Hays on May 19, 1926. A good stand was obtained of this legume, which grew 1 to 2 feet tall, retained its leaves long after frost, and developed a strong root like sweetclover, resisting successfully any ordinary effort to pull it. No flowers or seed pods were noted, nor did plants appear in 1927. However, 10 plants came up as volunteers in the spring of 1928, possibly from hard seed that had remained in the ground since 1926. They grew rapidly like second-year sweetclover, and by August the largest plant suggested at a distance a coarse nonflowering rose bush 5 feet tall. This plant sent up 14 hard, woody, scantily leafed stems three eighths to one half inch in diameter. Seed pods matured in thorny clusters about 1 inch in diameter and 2 or 3 inches long. Each cluster contained many flat prickly pods, and each pod usually contained two greenish-black legumelike seeds. The leaves were compound, with 8 to 12 opposite leaflets and a terminal one. The plant did not bear flowers in the popular sense of the term, and it seemed to have no value for any purpose.

### MISCELLANEOUS CROPS

#### SUNFLOWERS

Mammoth Russian sunflowers were tested at Hays in 1913 and 1914, and from 1920–24, inclusive. They were seeded between May 14 and June 2 in cultivated rows usually 40 inches apart. This may have been too late for best results, for it was noted that they came up and began growing vigorously under conditions too cold and wet for sorghums; it was also found that if more than one date of seeding was made, the sunflowers usually did best in the earliest one.

The size attained by the sunflowers varied from as little as 1½ feet in the severe season of 1913 to a maximum of 10 feet for individual plants under favorable conditions in 1922. Results were fairly uniform, however, in that the plants ceased growth on account of disease at or shortly after the first-bloom stage (fig. 27). The only seed crop obtained was in 1914, estimated at 200 to 300 pounds per acre, when heads developed before disease and insect attacks became too acute.

Forage yields were recorded only in 1921 and 1922. In 1921, about a normal year, the sunflowers were credited with 3.2 tons of silage per acre; in 1922, an exceptional year, the silage yield was 11.83 tons. In 1922 the forage yield was only 2.18 tons when reduced to an air-dry

basis. The crop was entirely destroyed by hail on June 29, 1923. An indication of relative yields for the other seasons may be gained from the average height of the plants, which was 1.5 feet in 1913, 5.5 feet in 1914, 5.5 feet in 1920, 4.5 feet in 1921, 8 to 9 feet in 1922, and 2 to 3.5 feet in 1924.

Other sunflower varieties tested were still less promising than Mammoth Russian. White Beauty, grown in 1921, was the earlier by 10

FIGURE 27.—Mammoth Russian sunflowers. The leaves are beginning to fall, due to attacks of disease and the effect of drought.

days, but less leafy and vigorous. S.P.I. 46757 and 46758 from Uruguay, grown in 1922, reached 7.5 feet in height, but yielded only 6.61 and 6.35 tons of silage per acre, respectively, as compared with 11.83 tons for Mammoth Russian. Burbank Prolific White, F.C. 04261, and Mantica, F.C. 04264, were also tested in 1922, but died early when only 2½ to 3 feet tall.

Failure of the sunflowers at Hays was caused in some degree by drought, grasshoppers, insects, and grubs within the stems, lodging

associated with an unexplained digging around the base of plants, and to a leaf rust.

The experiments at Hays indicate no profitable use for sunflowers in this section. If the plants escaped disease until matured, they could be used for silage, but even then they would have to exhibit some advantage over sorghums, which already serve this purpose adequately. Experiment-station reports from Montana and other high-altitude sections indicated for several years that sunflowers might be grown for silage in areas too cold and with too short a season for corn and sorghums, but even this prospect has faded on account of widespread attacks of the Sclerotinia wilt.

### RAPE AND KALE

Dwarf Essex rape was grown during seven seasons at the Fort Hays station, usually for hog pasture, on small fields of a few acres. In 3 years of favorable climatic conditions, 1902, 1912, and 1915, rape was seeded on bottom land and made satisfactory growth. During three dry seasons, 1910, 1911, and 1916, when it was seeded on upland, the crop made a small and unprofitable growth, due to drought and grasshoppers. Rape on upland in a fairly good year, 1920, was ruined by hot winds and insect pests during July. Thousand-headed kale beside the rape also failed for the same reasons. For best results, rape and kale need a cooler and more humid climate than that of Hays. They cannot compete profitably with Sudan grass as a hog pasture under western Kansas conditions.

### ROOT CROPS

Sugar beets, mangels, and possibly other root crops were grown on bottom land at the Hays station during most of the years from 1902 to 1909. They were usually irrigated, and yields of 10 tons or more were often obtained. Sugar beets were used satisfactorily as succulent winter feed for dairy cows and also for hogs and poultry. Their culture was discontinued, however, when silos came into use, for sorghums then furnished a more economical source of succulent feed. Sugar beets are considered about the most nutritious of the roots and mangels the highest in tonnage. Both do well under irrigation but are not suited to general dry-farming conditions.

In 1920 a $\frac{1}{10}$-acre plot of each of several root crops was seeded on upland in 40-inch rows. The test included three varieties each of mangels, rutabagas, and carrots. Weed competition was very severe. The rutabagas failed to stand the drought and insect attacks in July. The other crops, being thinner and more irregular in stands, suffered less. The carrots produced very little and were not harvested, but a quantity of mangels, sufficient to fill a barrel for a silage test, was harvested and produced a slimy unpalatable silage. Pigweeds, hemp, and tame sunflowers ensiled in separate barrels retained their color, showed acidity characteristic of corn and sorghum silage, and were palatable to cattle.

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# THE INFLUENCE OF PRECIPITATION AND GRAZING UPON BLACK GRAMA GRASS RANGE

BY

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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WASHINGTON, D.C.

# THE INFLUENCE OF PRECIPITATION AND GRAZING UPON BLACK GRAMA GRASS RANGE

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## THE IMPORTANCE OF BLACK GRAMA ON SEMIARID SOUTHWESTERN RANGES

The excellent stand and growth of palatable perennials that once covered much of the semiarid range lands of the Southwest afforded abundant feed for a thriving livestock industry. Where such conditions still prevail, and management is adjusted to sustain production of feed within the limits of climatic conditions, livestock production is effective. On most of the range, however, continued overstocking and the consequent accumulation of ill effects of overgrazing, combined with recurring drought, have brought about conditions involving not only heavy losses to the livestock producer but even

[1] The writer gratefully acknowledges his indebtedness to the members of the Jornada Experimental Range staff for field data collected from 1915 to 1927, and to these and other members of the Forest Service for constructive criticism of this report.

a complete failure of profitable production. How to restore the productivity of these lands is an urgent question, but one with many ramifications. One very important consideration is the preservation of the best of the remaining forage and the extension of its present growth. In this connection, one species of perennial grass growing on a considerable part of the semidesert range deserves primary attention. This is both because of its high palatability and its ability to extend its growth abundantly under moderately favorable circumstances, in which particulars black grama (*Bouteloua eriopoda*) is without a peer.

Originally, black grama was the mainstay of the range,[2] occurring rather abundantly and in almost a pure type over extensive areas of southeastern Arizona, southern New Mexico, western Texas, and south into Mexico. As such stands deteriorated black grama died out to a considerable degree, but the plant still occurs as important range forage on extensive areas, either in almost pure stands or mixed with other perennial grass species. Black grama is characteristically drought-resistant, a quality indispensable to the maintenance of any range forage plant under the climatic conditions prevailing in the Southwest. It is highly palatable and nutritious both in summer and winter, making it a valuable year-long forage plant, especially for cattle. During some winters the stems remain green up to about the second node from the top, and clusters of leaves may come out at the nodes the following spring. Black grama ordinarily cures well on the stalk and retains its nutritive value through the dry spring period when other range forage is parched and harsh.

Although the plant can withstand recurrent grazing by livestock, too heavy utilization impairs its vigor. During drought periods plants so weakened succumb, thereby greatly depleting the stand. It is of the greatest importance, therefore, to know just what degree of grazing use can be applied without injury to black grama ranges.

This bulletin presents the results of study, during the 13 years from 1915 to 1927, inclusive, of the influence of the variable precipitation and several intensities of grazing on the black grama range type on the Jornada Experimental Range (formerly Jornada Range Reserve) and adjacent public-domain range in southern New Mexico. The adoption on southwestern ranges of such principles as this study has brought to light should make the range cattle business of the region much more stable and profitable.

## METHODS OF STUDY

The Jornada Experimental Range of the Southwestern Forest and Range Experiment Station,[3] located in southern New Mexico, contains approximately 190,000 acres of grazing land typical of the southwestern semiarid region. It is mainly a flat to slightly rolling plain varying in elevation from approximately 4,100 to 4,700 feet above sea level. The east portion consists of the western slope of the San Andres Mountains, which rise to an elevation of 8,000 feet. Prior to 1904 the land now in the range was poorly watered for livestock grazing. There were a few springs in the mountains and inter-

[2] WOOTON, E. O., and STANDLEY, P. C. THE GRASSES AND GRASSLIKE PLANTS OF NEW MEXICO. N.Mex. Agr. Expt. Sta. Bull. 81. 175 pp., illus. 1912.

[3] Maintained in cooperation with the University of Arizona.

mittent lakes on the flats. Subsequent development of watering places, consisting of deep wells and reservoirs to catch flood waters, made the area a well-watered range unit.

The vegetation of the range consists of approximately 80 percent of perennial grasses and is grouped more or less distinctly into range vegetative types. The perennial grasses of these vegetative types are palatable to cattle either in the summer and fall or year long. Black grama is the dominant species on the year-long grass range.

The aim on the experimental range has, in the main, been so to stock the various pastures as to provide sufficient range feed for the cattle grazing on the range in practically every year. In the original plans all pastures were to be grazed to their capacity, certain ones year long, and others unusually lightly during the summer and fall with stocking heavier throughout the winter and spring in order to utilize the year's feed supply by the close of the spring grazing season. Short feed resulting from drought caused heavier utilization of feed than was originally planned, especially near the watering places. On the open public-domain range there was no control or regulation and the owner of the livestock grazing there utilized the range as he desired, which, in combination with the drought which prevailed in most years, resulted in overstocking in nearly every year up to 1926. Careful record was maintained through the period of the study as to the character and degree of use on each of the main parts of the black grama range. In order to have accurate and specific measurements of changes in the vegetation, plots or quadrats were established on areas representative of each of the main grazing conditions.

In Figure 1 is shown the location of the different series of quadrats used in the study. Each quadrat was 1 meter square, and 38 in all were included. Six of these, located in small fenced areas near headquarters and South Well,[4] were continuously protected from grazing by livestock.

For the most part the grazed quadrats were situated at ½-mile or 1-mile intervals along lines radiating out from the permanent watering places. Grazing was heaviest near these watering places, but gradually diminished at greater distances. The combination of the grazing practice for each range area on the Jornada range and the unfenced public domain, as well as the location of the quadrats, made it possible to segregate and compare with the protected areas the following intensities of grazing: (1) Conservative grazing year after year (10 quadrats); (2) heavy overgrazing year after year (10 quadrats); (3) full use in the better years and slight overgrazing in dry years (9 quadrats); and (4) overgrazing during the summer growing season year after year (3 quadrats). Observations were begun in 1915 and 1916, except on 2 of the protected quadrats, 2 of those conservatively grazed, and the 3 summer-overgrazed; on these 7 plots observations were begun in 1919.

Conservative grazing was considered to be that wherein only 75 to 80 percent of the annual growth of black grama, on the average, was utilized at the end of the grazing season of each year. Lighter graz-

[4] Four of these were first fenced from livestock in 1913, 1 in the spring of 1916, and 1 in 1919.

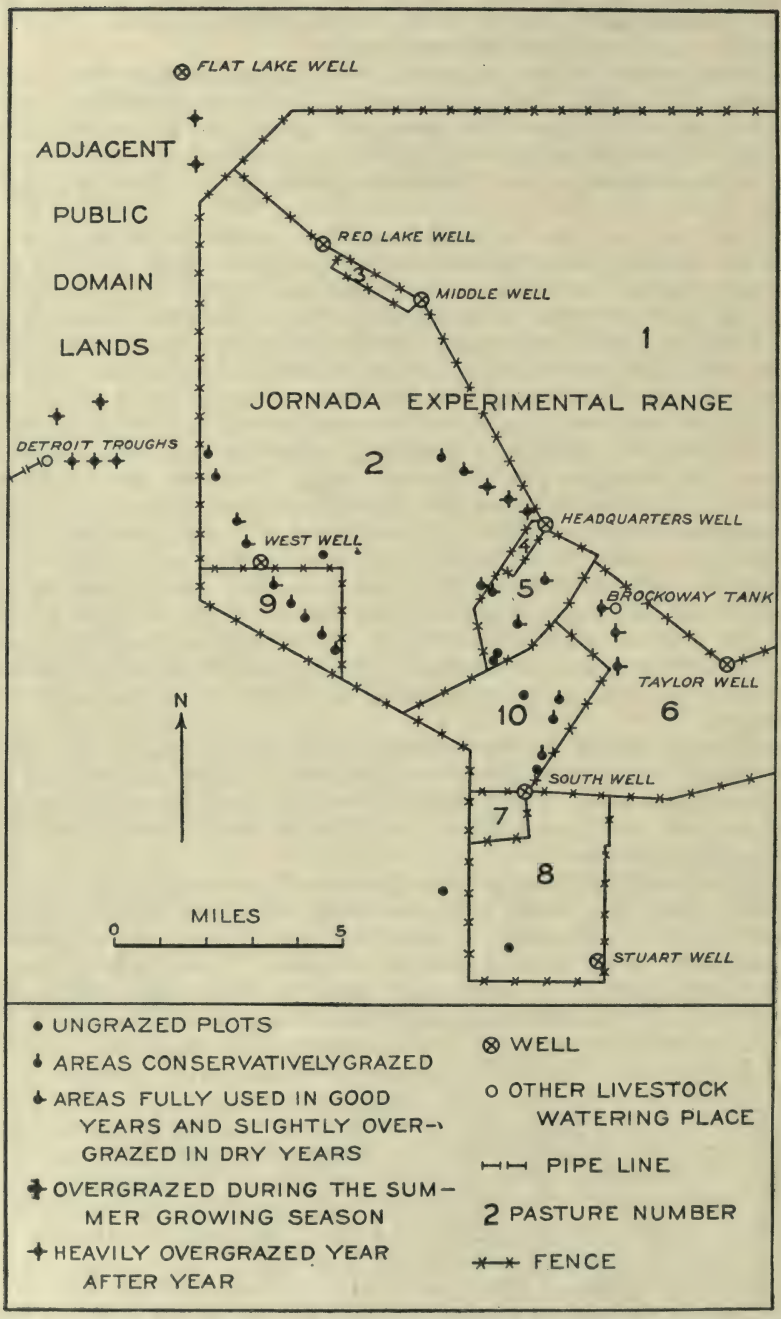



FIGURE 1.—Map of a portion of the Jornada Experimental Range and adjacent public domain, showing the location of the different series of quadrats used in these experiments.

ing use occurred in the better years and heavier use during the driest years. Since all of the forage was not utilized until the end of the grazing year it will be evident that there was light use during the summer growing season each year and the more palatable plants, especially black grama, were given the maximum opportunity permitted under grazing use to make a vigorous growth and reproduce.

Under heavy overgrazing year after year the annual growth of black grama was completely utilized and the range was considerably trampled by the end of the grazing season both in average years and in drought years. Because of the high palatability of the black grama, it was fairly heavily grazed each year from the time that growth started. This degree of use occurred, except at remote distances from permanent water, on the open public-domain range adjacent to the Jornada Experimental Range.

On the areas where full use prevailed in the better years and slight overgrazing in dry years, approximately 85 percent of the annual growth of black grama was utilized at the end of grazing years of more favorable rainfall. There was less trampling and lighter use of the less palatable species than on the areas heavily overgrazed year after year. In dry years the black grama was completely utilized. In most years grazing was moderate during the summer growing season.

The fourth degree of grazing use was comparable to the second, except that the grazing took place during the summer and fall seasons only. The quadrats used to show this degree of grazing were located in small areas of black grama found on interspersed sandy ridges in summer range. Tobosa grass (*Hilaria mutica*) was the important summer range forage and was most palatable during the summer and fall.

After 1925 all of the range areas under study were lightly grazed or ungrazed.

The quadrats were charted each year to determine the changes in area of the vegetation. In the earlier years of the study this was done both in the late spring and near the end of the normal growing season in the fall; later it was done only in the fall. The boundary of each perennial-grass tuft at a point 1 inch above the soil surface was accurately mapped, recorded on a quadrat sheet, and its area computed in square centimeters as the basis of comparison between years. Other perennial herbaceous plants were located on the sheet and the number totaled for each quadrat by species. The annual grasses and weeds were counted by decimeter strips or squares and recorded on the quadrat sheet.

Observations and measurements of black grama and associated grasses were made annually on each quadrat and on the nearby surrounding area, the data recorded including the following: (1) Period of growth; (2) dates of flowering, seed ripening, seed maturity, and seed dissemination; (3) maximum and average height growth of flower stalks and length of leaves; and (4) the general condition of the vegetation and soil. Observations were also made over each range area of the annual forage crop as compared to the average at the close of the summer growing season, and of the extent of utilization of the forage crop at the close of the grazing year.

An accurate record of the forage volume produced in each year on the parts of the range grazed to different intensities would have been desirable. However, no method has been developed to obtain such data accurately and practically on southwestern semiarid ranges under grazing use. While the clipping of black grama on small plots to obtain forage volume has shown distinct values, the results have not proved entirely satisfactory for comparison with forage production on the areas actually grazed. Clipping treatment so far applied to black grama differs from actual grazing and gives different results.[5] For these reasons, the principal comparisons in this bulletin are on the basis of plant area and height growth, definitely measurable quantities indicative of forage production and demonstrably useful in developing practical range management.

Seed germination tests of several of the grasses were made in the laboratory by the United States Bureau of Plant Industry in 1917, 1919, 1920, and 1921; by the New Mexico College of Agriculture and Mechanic Arts from 1922 to 1925, inclusive, and by Carola V. Jackson, University of Chicago, in 1926.

Records of daily maximum and minimum air temperatures and of precipitation were obtained at the Jornada headquarters in cooperation with the United States Weather Bureau for the 12 years from July 1, 1915, to June 30, 1927, inclusive, and precipitation records at South Well and West Well for the 9 years from July 1, 1918, to June 30, 1927, inclusive. Records maintained since 1861 at State College, N.Mex., about 25 miles south of the Jornada headquarters, were also available as a valuable check on the data gathered locally. Records of precipitation at several other Weather Bureau stations in southern New Mexico were also studied to determine the relation of the period of this study to the available long-time record.

## BLACK GRAMA ON THE RANGE

Black grama, also referred to as "woolly-foot grama," is a tufted, branching, strong-rooted, long-lived perennial grass easily identified by the characteristically open, flag-like seed heads. The stems are woolly, especially the lower parts, and vary from 3 to 36 inches in height. The longer stems are the result of favorable growing conditions in one or more years, since the stems do not die entirely back to the crown of the plant each year. Furthermore the stems may branch from axillary buds which form at the nodes or joints. The leaves are smooth and narrow and from 1 to 5 inches in length. Variation in stem height and foliage growth is related mainly to climate, soil, and vigor of the plants, which rarely grow dense enough to form a sod. If ungrazed for a number of years, black grama tends to form a rather uneven stand of large tufts. During drought these die out in the center and break up into many smaller tufts. With a return of favorable climatic conditions these smaller tufts enlarge again and may grow together. Where grazed, the tufts are on the average smaller and generally more evenly distributed over the soil surface. Even under grazing use, plants have remained

[5] CULLEY, M. J., CAMPBELL, R. S., and CANFIELD, R. H. VALUES AND LIMITATIONS OF CLIPPED QUADRATS. Ecology 14: 35–39. 1933.

alive for the 13 years that the black grama range has been under intensive study.

The range of black grama extends from western Texas, through New Mexico and Arizona, south into Mexico, where the grass occurs in the semiarid grassland, yucca-grass, or grass-shrub formations of valley and tableland. The main altitudinal range of the species is from 3,500 to 5,500 feet, although it is occasionally found below 3,000 or above 7,000 feet. It occurs mainly in open grassland areas, commonly on the well-drained sandy or gravelly soils of dry mesas so characteristic of southern New Mexico. Here, in what is doubtless its maximum development, it becomes the dominant plant of the climax plant formations. It occurs less commonly in the foothills, only rarely on clay loams and adobe flats, and seldom anywhere under the shade of dense brush.

Black grama is found at its best on the compacted sandy soils of the dry mesas. Here it occurs in almost pure stands (pl. 1, *A*), covering 30 to 40, and occasionally up to 60, percent of the soil surface.

### GROWTH HABITS

The period of growth of black grama in southern New Mexico is determined primarily by precipitation and temperature. Occasionally, when precipitation during the fall, winter, and spring is sufficient and temperatures are not too low, some growth of leaves takes place in March and April; with continued favorable moisture, growth continues into the main summer growing period. Continued growth from spring to summer is, however, very unusual; if any growth occurs in the spring it usually ceases in May or June because of the very light precipitation and the severe drying winds common during that period. The main growing season starts with the beginning of the summer rainy period, ordinarily early in July, though it may begin during May or June or as late as August 1 to 15. If rainfall is adequate and evenly distributed growth continues until late September or even through October.

The time of flowering and fruiting varies with the beginning of the summer growing season. With average amount and distribution of rainfall during this period flower stalks are produced in 5 to 7 weeks after growth starts. Hence, ordinarily, the flowering period may be expected the early part of August and the fruiting period the latter part of September. Seed dissemination begins in October and extends into November. Infrequently two flowering periods occur in the same year, as in 1926 on the Jornada Experimental Range. In that year abundant rainfall during May brought on an early flowering period, and excellent rains during July produced a second. However, dry periods in June and again in August prevented the maturing of seed in both growing periods.

The chief methods of revegetation of black grama are by lateral spread and by stolons. In the process of lateral spread, the area of the individual plant is increased by new stems arising from the outer edge of the root crown, a process which is commonly termed "tillering."

In revegetation by stolons (pl. 1, *B*), the flower stalks or stems bend over to the ground or, less frequently, grow horizontally just above the surface of the ground from the base of the parent plant.

On these stolons, small clusters of leaves form from axillary buds at the nodes or joints; these, under favorable climatic conditions, take root and grow into new plants, known as sets. The stems which connect the new plants with the parent plant, if not broken by trampling, persist for 2 years, or until the sets have become established and are no longer dependent on the parent plant for sustentation. At least 60 percent of the sets are formed beyond the second node of the stolon. Ordinarily, the sets of one year are formed on stems produced during the previous year. Formation of stolons and new sets in the same year occurs if there is good rainfall and a long growing season. Good precipitation during May and June may result in stolons being produced before the main summer growing season. The continuous process of revegetation by stolons may be referred to as "progressive revegetation," since plants established by stolons will eventually send out fresh stolons during subsequent favorable growing seasons, and these in turn will establish new plants.

### ASSOCIATED SPECIES

Soapweed (*Yucca elata*), in scattered stands, is characteristic of the black grama type, especially on the compacted sandy soils of dry mesas. Numerous other plant species, including both perennial and annual grasses and weeds (nongrasslike herbaceous plants), also occur in the black grama type. Most of these are normally scattered and of little importance, but many of them invade the type in profusion in years of abnormal growing conditions or in favorable seasons following the depletion of the black grama stand by drought or overgrazing. All are inferior to black grama in forage value, although many of them furnish some variety in the feed and aid in bolstering up the grazing capacity of the ranges. However, the invasion of the more persistent and aggressive species, owing to competition for the available soil moisture, may delay the reestablishment of black grama. The habits of growth and revegetation of these species, which are largely limited by precipitation and other growing conditions, influence their invasion and stability in the black grama type.

The associated species may be classified roughly as long-lived perennials, short-lived perennials, and annuals. The chief perennial grasses associated with black grama in the Jornada region are the three-awn grasses (*Aristida longiseta robusta*, *A. Pansa*, and *A. purpurea*), and the sand dropseed grasses (*Sporobolus flexuosus* and *S. cryptandrus*). These species are more common on the looser sandy soils of the grama type.

The seed habits of these grasses afford them an advantage in the revegetation of range areas that have been depleted by drought, overgrazing, or other cause. In years when good moisture conditions prevail in the spring, especially in April, substantial foliage growth results. When growing conditions continue favorable, which rarely happens, the three-awn grasses mature their seed by June 15. Under such conditions a second seed crop of these species is produced during the summer growing season of the same year. These grasses are good seeders, and seedlings become established in the same year the seed is scattered or in the year following, if favorable conditions prevail.

The growth and seed habits of the sand dropseed grasses are similar to the three-awn grasses except that they do not produce their better crops of seedlings until the first favorable growing season following a period of drought. This ability of the dropseed grasses to spring up from seed after drought is especially important because it enables them to establish themselves on sandy soils which have become loosened following the depletion of black grama through drought or overgrazing. The more abundant stands of seedlings come in on these depleted areas; in fact there is usually scant seedling establishment where the stand of black grama is dense.

The chief long-lived perennial weed associates are baileya (*Baileya multiradiata*), leatherweed (*Croton corymbulosus*), evolvulus (*Evolvulus pilosus*), *Hoffmanseggia* spp., woolly paperflower (*Psilostrophe tagetinae*), and silvery nightshade (*Solanum elaeagnifolium*). These species ordinarily occur sparsely scattered throughout the black grama type. They are all deep rooted and survive severe drought well, although they develop only scant foliage during such periods.

Snakeweed (*Gutierrezia sarothrae*),[6] a half shrub with growth characteristics similar to those of weeds, is a fairly long-lived plant which almost invariably invades areas that have been depleted of black grama by the persistence of overgrazing for several years. A vigorous stand of the species is one of the best indications of past or present overgrazing in the black grama type. Under favorable climatic conditions it produces abundant seed, resulting in many seedlings which become firmly established where the black grama stand is depleted. Black grama successfully competes with snakeweed if the range is conservatively grazed.

The short-lived perennial weeds most common in the black grama type are spectaclepod (*Dithyræa wislizeni*), and stickleaf, or "whitestem" (*Mentzelia multiflora*). These weeds do not live more than 2 or 3 years. The plants usually do not make much growth until shortly after the beginning of the summer rainy season. They occur in more or less abundance in the more nearly average years, are scarcely noticeable during protracted droughts, and spring forth in great abundance in the first favorable season. They compete somewhat with black grama for soil moisture during these periods.

The more prominent annual plants in the black grama type are several weeds including *Boerhaavia torreyana*, mouse-ear (*Tidestromia lanuginosa*), eriogonum (*Eriogonum* spp.), and six-weeks grasses (*Aristida adscensionis*, *Bouteloua aristidoides*, and *B. barbata*).

Many of the annual weeds make some growth during the late winter and early spring months, except in the extremely dry years. They make excellent growth during the very occasional unusually wet summer or moist, warm, late winter and spring. Ordinarily, however, their growth is dependent on late spring or summer rainfall. In most years when sufficient moisture is available the growth to maturity of annual weeds is more rapid than that of the perennials. The weed seeds, lying very close to the surface in the upper soil layer, are warmed by rising spring temperatures earlier than

[6] *G. sarothrae* is considered in this report to include *G. juncea*, *G. longifolia*, and *G. tenuis* in accordance with the treatment of Dr. S. F. Blake, composite expert of the Bureau of Plant Industry.

are perennial plant roots spread out some distance below the surface. As a result, germination and early growth are in advance of the appearance of the perennials. Ample precipitation during the fall and winter does not always bring weed growth, however, since low temperatures during the late winter and early spring may prevent growth entirely.

These annuals may make some growth even during drought. The scattered light showers that occur at such times are usually sufficient to germinate the seed and allow for some growth, often to maturity. When a favorable year follows a prolonged drought a luxuriant growth of annuals is generally produced, because of the lack of severe competition from the depleted stand of perennial grasses. These annuals produce some range feed in their early stages of growth and serve as protection against wind erosion until perennials take hold.

## INFLUENCE OF PRECIPITATION

The natural habitat of black grama is normally one of low rainfall, high temperatures, high evaporation, and relatively severe winds. It is further subjected to marked variation in these factors from year to year and season to season, especially with respect to rainfall. Although the growth, maintenance, and revegetation of black grama vary to some degree with all of these climatic variations, the correlation between variations in rainfall and the response of black grama is noticeably high.

### PRECIPITATION RECORDS

From long-time records taken prior to 1920, Jardine and Forsling [7] concluded that in southern New Mexico, in cycles of 8 to 10 years, there may occur 3 or 4 consecutive years during which precipitation is enough below its mean to cause conditions considered by stockmen as drought.

The monthly, seasonal, and annual rainfall for the Jornada headquarters for the period July 1, 1915, to June 30, 1927, and for South Well and West Well from July 1, 1918, to June 30, 1927, are given in table 1. The 12-month period from July 1 to June 30 of the following year is considered the rainfall year because of the influence of precipitation during this period on the maintenance, decline, and spread of the black grama stand from year to year and because the summer growing period which produces the main feed for the year ordinarily begins in July.

[7] JARDINE, J. T., and FORSLING, C. L. RANGE AND CATTLE MANAGEMENT DURING DROUGHT. U.S. Dept. Agr. Bull. 1031, 84 pp., illus. 1922.

TABLE 1.—*Precipitation during the grazing year and the summer growing season, Jornada Experimental Range*

HEADQUARTERS

| Grazing year | July | Aug. | Sept. | Oct. | Nov. | Dec. | Jan. | Feb. | Mar. | Apr. | May | June | Summer season [1] | Year |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1915–16 | 1.40 | 1.91 | 1.55 | 0.00 | 0.00 | [2]0.25 | 0.25 | 0.47 | 0.79 | 0.05 | 1.45 | 0.00 | 4.86 | 8.12 |
| 1916–17 | .90 | .96 | .72 | 2.63 | .47 | .19 | .47 | [3] T | T | .02 | .39 | .05 | 2.58 | 6.80 |
| 1917–18 | .57 | 1.52 | .25 | .11 | .16 | .00 | .78 | .09 | T | T | .05 | .09 | 2.34 | 3.62 |
| 1918–19 | 1.53 | 2.88 | .00 | .96 | 1.71 | .67 | .00 | .00 | 1.50 | .83 | .28 | .11 | 4.41 | 10.47 |
| 1919–20 | 3.13 | 2.52 | 2.55 | .64 | .72 | .50 | .69 | .42 | .35 | .03 | .97 | 1.53 | 8.20 | 14.05 |
| 1920–21 | 1.50 | 3.28 | .89 | 2.16 | .20 | .00 | .17 | .15 | .25 | .12 | .00 | 1.00 | 5.67 | 9.72 |
| 1921–22 | 1.50 | 1.26 | .73 | .16 | .17 | .21 | .30 | .00 | .06 | .30 | .00 | .11 | 3.49 | 4.80 |
| 1922–23 | .25 | 1.80 | 1.13 | 2.11 | .43 | .20 | .38 | 1.16 | .78 | .29 | .00 | .65 | 3.18 | 9.18 |
| 1923–24 | .68 | 1.53 | 1.74 | .21 | .57 | 1.49 | .16 | .11 | .51 | .15 | .19 | .11 | 3.95 | 7.45 |
| 1924–25 | 3.34 | .32 | .21 | .30 | .15 | .42 | .03 | .28 | .05 | .02 | .87 | .11 | 3.87 | 6.10 |
| 1925–26 | 1.68 | 1.19 | .89 | 1.50 | .00 | .31 | .49 | .05 | 1.40 | .48 | 2.43 | .06 | 3.76 | 10.48 |
| 1926–27 | 4.95 | .38 | 3.20 | 2.63 | .04 | 1.62 | .02 | .25 | .47 | T | .00 | .08 | 8.53 | 13.64 |
| Mean: | | | | | | | | | | | | | | |
| 1915–27 | 1.79 | 1.63 | 1.16 | 1.12 | .38 | .49 | .31 | .25 | .51 | .19 | .55 | .32 | 4.57 | 8.70 |
| 1918–27 | 2.06 | 1.68 | 1.26 | 1.19 | .44 | .60 | .25 | .27 | .60 | .25 | .53 | .42 | 5.01 | 9.54 |

SOUTH WELL

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918–19 | 1.55 | 0.84 | 0.00 | 1.15 | 0.70 | 0.31 | 0.20 | 0.20 | 1.06 | 0.00 | 0.02 | 0.42 | 2.39 | 6.45 |
| 1919–20 | 1.75 | 1.63 | 1.29 | .42 | .60 | .34 | .42 | .08 | .15 | .03 | .56 | 1.64 | 4.67 | 8.91 |
| 1920–21 | 1.05 | 3.66 | .57 | 1.83 | .15 | .00 | .00 | .11 | .10 | .06 | .00 | 1.40 | 5.28 | 8.93 |
| 1921–22 | 1.69 | .67 | .79 | .11 | .23 | .27 | .57 | .00 | .07 | .23 | .00 | .19 | 3.15 | 4.82 |
| 1922–23 | .51 | 2.20 | .98 | 1.03 | .49 | .19 | .06 | 1.03 | .97 | .34 | .00 | .00 | 3.69 | 7.80 |
| 1923–24 | .76 | 1.74 | .38 | .40 | .57 | 1.11 | .19 | .07 | .51 | .00 | .07 | .00 | 2.88 | 5.80 |
| 1924–25 | 2.81 | 1.17 | .28 | .33 | .43 | .45 | T | .09 | T | T | 1.38 | .29 | 4.26 | 7.23 |
| 1925–26 | 1.03 | 1.26 | 1.87 | .98 | .00 | .18 | .53 | .00 | 1.57 | .91 | 2.09 | T | 4.16 | 10.42 |
| 1926–27 | 4.01 | .25 | 3.48 | 2.61 | .01 | 1.84 | .03 | .34 | .51 | .00 | .00 | .10 | 7.74 | 13.18 |
| Mean | 1.68 | 1.49 | 1.07 | .98 | .35 | .52 | .22 | .21 | .55 | .17 | .46 | .45 | 4.25 | 8.17 |

WEST WELL

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918–19 | 1.00 | 1.99 | 0.17 | 1.00 | 0.65 | 0.41 | 0.00 | 0.12 | 1.25 | 0.00 | 0.10 | 0.03 | 3.16 | 6.72 |
| 1919–20 | 2.86 | .40 | 1.70 | 1.16 | .79 | .50 | .53 | .43 | .18 | .00 | .52 | 2.16 | 4.96 | 11.23 |
| 1920–21 | 2.62 | 4.19 | .63 | 1.95 | .21 | .00 | .00 | .00 | .01 | .00 | .00 | 1.00 | 7.44 | 10.61 |
| 1921–22 | 3.87 | 1.10 | .56 | .67 | .12 | .22 | .25 | .00 | .00 | .36 | .00 | .03 | 5.53 | 7.18 |
| 1922–23 | 1.56 | 1.07 | .49 | 1.79 | .55 | .13 | .11 | 1.64 | 1.15 | .46 | .00 | .00 | 3.12 | 8.95 |
| 1923–24 | .24 | 2.65 | .64 | .39 | .50 | 1.01 | .11 | .15 | .42 | .20 | .24 | .00 | 3.53 | 6.55 |
| 1924–25 | 1.40 | .12 | .30 | .28 | .13 | .22 | .04 | .07 | .09 | .15 | 1.30 | .00 | 1.82 | 4.10 |
| 1925–26 | 1.50 | 1.47 | 1.04 | 1.04 | .00 | .36 | .55 | .00 | 1.66 | .71 | 1.98 | T | 4.01 | 10.31 |
| 1926–27 | 2.48 | 1.66 | 4.81 | 2.53 | .12 | 2.03 | .02 | .23 | .25 | .00 | .00 | .04 | 8.95 | 14.17 |
| Mean | 1.95 | 1.63 | 1.15 | 1.20 | .34 | .54 | .18 | .29 | .56 | .21 | .46 | .36 | 4.72 | 8.87 |

[1] July, August, September. [2] Interpolated. [3] T=Trace.

A study of the data in table 1 shows that precipitation in the Jornada area is highly variable. The headquarters, South Well, and West Well are all less than 8 miles apart (fig. 1). Analyses made from this table show that the amount of precipitation varies significantly between (1) years, (2) the four seasons of summer, fall, winter, and spring, (3) the three stations, (4) years for the same season, and (5) years for the same station. While there is doubtless an influence on black grama in some degree of each of these significant variations in precipitation, the study has not been carried far enough to show conclusively the influence of each. In range management the stand and vigor of black grama in any one year are mainly influenced by the precipitation of the 12 months preceding, beginning July 1. The influence of the other variations on plant growth shows up only locally or in occasional years or seasons.

The average annual precipitation at the Jornada headquarters for the 12-year period of 8.70 inches, and the average for July, August, and September (the usual summer rainy season and the main growing period) of 4.57 inches, compare well with the long-time average annual precipitation of 8.57 inches and the summer-season average of 4.76 inches recorded at State College. The annual precipitation at State College ranged from as low as 3.94 in 1874–75 to as high as 16.13 inches in 1902–3, as compared to the low year on the Jornada of 3.62 inches in 1917–18 at headquarters and the high of 14.17 inches in 1926–27 at West Well.

During the 12-year period July 1, 1915, to June 30, 1927, according to the data recorded at the Jornada headquarters, the second, third, seventh, and tenth years were materially below the average annual precipitation for the 12-year period. Of the others, the fifth (1919–20) and the twelfth (1926–27) were materially above average in annual precipitation.

It is, of course, important to understand to what degree the general averages of precipitation during the 12-year period recorded at Jornada headquarters are representative of the long-term averages for this region. The records at State College and at other points in the Southwest indicate a general deficiency in precipitation for the period 1915–27. The average annual precipitation for the period July 1, 1915, to June 30, 1927, inclusive, at State College was 7.82 inches, or 8.8 percent below the long-time mean. The deficiency in average annual precipitation at El Paso, Tex., Elephant Butte Dam, and Deming, N.Mex., for the period 1915 to 1927 as compared to the long-time means for these stations, varied from 14.6 to 15.6 percent. The average deficiency for the four stations amounted to 13.2 percent for the period. It seems reasonable, therefore, to assume that the deficiency at Jornada headquarters from 1915 to 1927 was approximately 10 percent, or that the long-term mean precipitation at this station would be about 9.63 inches. On this basis, annual precipitation for 5 of the 12 years during which this study was conducted was above the computed mean—for 2 of them approximately 4 inches above; whereas for 7 years it was below the computed mean—for 5 of them 2 inches and more below.

For the 9-year period (July 1, 1918, to June 30, 1927) Jornada headquarters received an average annual rainfall of 9.54 inches; West Well, 8.87; and South Well, 8.17 inches. It is possible that the differences in rainfall between the several stations, as in the individual years, are more the result of uneven distribution of showers than a difference in the long-time mean annual precipitation. Ordinarily the summer rains in the semiarid region in which the Jornada range is located occur as showers covering a comparatively small area. In an occasional year, as in 1925–26, individual rains are more general and cover more extensive areas.

The average summer precipitation during the 12-year period from 1915–16 to 1926–27 at the headquarters ranch was 4.57 inches. From July 1, 1915, to June 30, 1927, there was an average deficiency in the summer precipitation at the State College station as compared to the long-time mean of 13.4 percent. At El Paso, Elephant Butte Dam, and Deming the summer deficiency based on years of complete records varied from 8.2 percent at El Paso, to as much as 17.7

percent at Elephant Butte Dam. The average deficiency for the four stations amounted to 13.1 percent. In view of the high deficiency at State College and Elephant Butte Dam, it appears reasonable to assume that the Jornada headquarters had a summer deficiency in these 12 years of at least 13 percent. Assuming that there was 13 percent deficiency, the long-term mean summer rainfall at the headquarters is 5.25 inches.

Thus in the 12-year period on the Jornada Experimental Range, only two growing seasons, 1919 and 1926, had 3 inches more rain than the computed long-time mean, and one other, 1920, had about one half inch more; the other years were below the computed mean. Of these, two groups of years are particularly significant—one of 5 years (1921–25) all approximately 1¼ to 2 inches below; and one of 2 years (1916–17) more than 2½ inches below the computed mean. These two groups of years represent low summer precipitation and uncertain plant growth. The summers of 1916 and 1917 were each more deficient in rainfall than any of the summers from 1921 to 1925, but the longer succession of dry summers in the latter period bred conditions more severe for plant growth.

To summarize, the relatively fair to good rainfall for several years prior to 1915 [8] was followed by deficient rainfall during the summer growing season or throughout the year on large areas of the experimental range annually from 1915 to 1918, inclusive. This dry period was followed by 2 years of favorable rains over most of the range. From the summer of 1921 until the spring of 1926, rainfall was again deficient, either during the summer season or year long, or both, over practically all parts of the range. This period of deficiency was followed by favorable rains, starting in the spring of 1926 and extending through the summer growing season of 1927. Rainfall at South Well and West Well was lower in most years than at the headquarters. It was much drier at these outlying stations in 1918–19; at West Well there was more rainfall in 1921–22 but less in 1924–25 than at the headquarters.

### PRECIPITATION AND PLANT GROWTH

Because of the fact that on the average approximately 90 percent of the range forage production in southern New Mexico is concentrated in the summer growing season and only 10 percent occurs in the spring, it is very important to study the influence on growth and reproduction not only of the quantity of rainfall but also of its seasonal distribution. This influence is apparent in the period and volume of growth of the important grasses each year, the density of the stand, the number and size of the tufts, the methods of reproduction, including the formation and the germination of seed and the establishment of seedlings, the lateral spread of the tufts, and the formation of stolons and establishment of sets. In these connections it is important to observe not only the precipitation during the particular season in question, but also the possible effect of excessive drought or rainfall during the preceding years.

As already indicated, rainfall of sufficient quantity to start appreciable growth of black grama does not occur in most years until

[8] LINNEY, C. E., and GARCIA, F. CLIMATE IN RELATION TO CROP ADAPTATION IN NEW MEXICO. N.Mex. Agr. Expt. Sta. Bull. 113, 132 pp. 1918.

July, when the normally heavy and frequent storms of July, August, and September are sufficient to make growth continuous during those months. Summer growth may start, however, in the normally dry period of May and June if sufficient rainfall occurs at that time, as in 1920 and 1926. In 1920, because of copious rains the latter part of May, forage started to grow the first week of June and continued growing throughout June, July, and August. In 1926 the exceedingly heavy rainfall in May brought early growth, which the deficiency in June retarded. Growth started up again with heavy rainfalls in July but was once more arrested by a deficiency in August. Such uneven seasonal rainfall, if abundant, as it was in 1926, produces a substantial forage crop.

The summer of 1924 is an example of the influence of unsatisfactory distribution of moisture during the summer. The rainfall of that summer occurred as heavy showers during July. This started good growth but was followed by a protracted dry spell during which there was not sufficient precipitation to maintain growth. When adequate summer rains do not start until the first of August or later, as in the summers of 1917, 1922, and 1923, the growing season is materially shortened, resulting in a greatly reduced forage crop. This is especially true when a late season is accompanied by deficient rainfall.

Plant growth is also affected by uneven geographical distribution of rainfall. For example, in the summer of 1919, in contrast with the even distribution of rainfall and the good growth which occurred over most of the range, the West Well area suffered a considerable setback. An excellent rain the first week of July and good moisture conditions during that month started forage growth at least one week earlier than on the other parts of the range, but by the end of August forage growth had practically ceased in that part of the range because of the scant precipitation locally in that month. Rainfall in September improved conditions only slightly. The uneven distribution of rainfall in a season when rainfall was not abundant seriously reduced the volume of growth and maturity of the vegetation near West Well.

During the 12-year period for which precipitation and growth records were taken on the Jornada range only 3 years had sufficient winter and spring moisture to encourage early spring growth although in these years such growth was appreciable. It is obvious, therefore, that winter-spring precipitation cannot be depended upon to produce a substantial forage crop in southern New Mexico. On the other hand the unusually dry winter and spring of 1921–22, which were accompanied by high winds, serious wind erosion and sand deposition, had a disastrous influence on the stand of black grama.

### HEIGHT GROWTH

Height growth was found to be a useful index to relative vigor and volume production of range grasses in different years. Black grama flower stalks on the ungrazed plots on the Jornada averaged 35.2 cm. (13.9 inches) in height from 1917 to 1927, inclusive. As shown in table 2 there was a rather direct relation between summer rainfall and height growth. It was found that a summer growing

season with precipitation much above the average resulted in a greater than average height growth, while a deficiency in precipitation during this period resulted in a stunted height growth for that season regardless of the conditions which prevailed during the previous year. An added inch of summer precipitation results in an average increase of height growth of 3.6 cm.

TABLE 2.—*Relation of rainfall during current summer[1] season at headquarters and South Well to average height growth of black grama flower stalks on areas continuously protected from livestock grazing, 1917 to 1927*

| Year | Average rainfall | Average stem height | Year | Average rainfall | Average stem height | Year | Average rainfall | Average stem height |
|---|---|---|---|---|---|---|---|---|
| | *Inches* | *Centimeters* | | *Inches* | *Centimeters* | | *Inches* | *Centimeters* |
| 1917 | [2] 2.34 | [2] 33.0 | 1921 | 4.52 | 30.3 | 1925 | 5.28 | 33.3 |
| 1918 | 3.40 | [2] 22.0 | 1922 | 3.44 | 28.3 | 1926 | 10.42 | 50.0 |
| 1919 | 6.44 | 42.7 | 1923 | 3.74 | 28.0 | 1927 | 6.28 | 38.0 |
| 1920 | 7.82 | 50.3 | 1924 | 4.06 | 31.7 | Average | 5.25 | 35.2 |

[1] Covers actual current growing season, including rainfall in May and June when this was effective.
[2] Average on one area only.

## PLANT AREA

The marked variation in precipitation characteristic of southern New Mexico has a very definite effect upon the stand of black grama. The tendency of a deficiency to reduce plant vigor and tuft area is no less evident than that of an above-average supply to build up plant vigor and area. The more pronounced changes in plant area ordinarily followed when one or other of the conditions prevailed from the beginning of one to the end of the subsequent summer growing season or longer, although intervening seasonal differences also have their effect in a smaller degree. This is shown in table 3 in plant area on the representative quadrats protected from grazing on the Jornada Experimental Range, in relation to the important summer and annual precipitation in their vicinity during the period 1915–27.

TABLE 3.—*Changes in area of black grama per square meter, at 1 inch above the ground, on ungrazed quadrats, in relation to precipitation of current summer and previous year at headquarters and South Well*

| Year | Average precipitation | | Average plant area | Year | Average precipitation | | Average plant area |
|---|---|---|---|---|---|---|---|
| | Previous year[1] | Summer[2] | | | Previous year[1] | Summer[2] | |
| | *Inches* | *Inches* | *Cm²* | | *Inches* | *Inches* | *Cm²* |
| 1915 | [3] 10.77 | [3] 4.86 | 548.2 | 1923 | 8.49 | 3.42 | 60.0 |
| 1916 | [3] 8.12 | [3] 2.58 | 537.1 | 1924 | 6.62 | 4.06 | 125.7 |
| 1917 | [3] 6.80 | [3] 2.34 | 461.7 | 1925 | 6.66 | 3.96 | 106.7 |
| 1918 | [3] 3.62 | 3.40 | 337.4 | 1926 | 10.45 | 8.14 | 283.4 |
| 1919 | 8.46 | 6.44 | 227.4 | 1927 | 13.41 | 6.28 | 277.9 |
| 1920 | 11.48 | 5.48 | 433.4 | | | | |
| 1921 | 9.33 | 3.32 | 534.3 | Average | 8.39 | 4.44 | 310.8 |
| 1922 | 4.81 | 3.44 | 107.6 | | | | |

[1] Precipitation for previous year covers July 1 to June 30.
[2] Summer rainfall covers July, August, and September of current growing season.
[3] Rainfall record for headquarters only.

The stand of black grama was unusually good in 1915. It had recovered from the severe drought of 1907 to 1912, partly because of the favorable climatic conditions of 1913, 1914, and 1915, and partly owing to the practice of conservative grazing during some of that time. A decline in area as a result of continued drought during 1916, 1917, and 1918 was followed by a partial recovery under the more favorable growing conditions of 1919 and 1920, and another, even more severe decline of longer duration as a result of deficient rainfall in 1921 and succeeding years. With the aid of the unusually favorable moisture supplies of 1926 and 1927, some areas recovered slightly and others more completely.

Since the main growth of black grama is produced during the summer months, the rainfall during that period might be expected to have the greatest effect on the change in area of plant cover in that year as compared to the area of the previous year. Actually, however, the current summer rainfall in itself has no significant effect on such change. The lack of influence of current summer rainfall is indicated by the practically negligible average decrease in plant area between 1915 and 1916, even though the summer precipitation of 1916, including that of June, was much below normal. Also, summer rainfall much above normal in 1919 failed to offset the loss of vigor from previous drought.

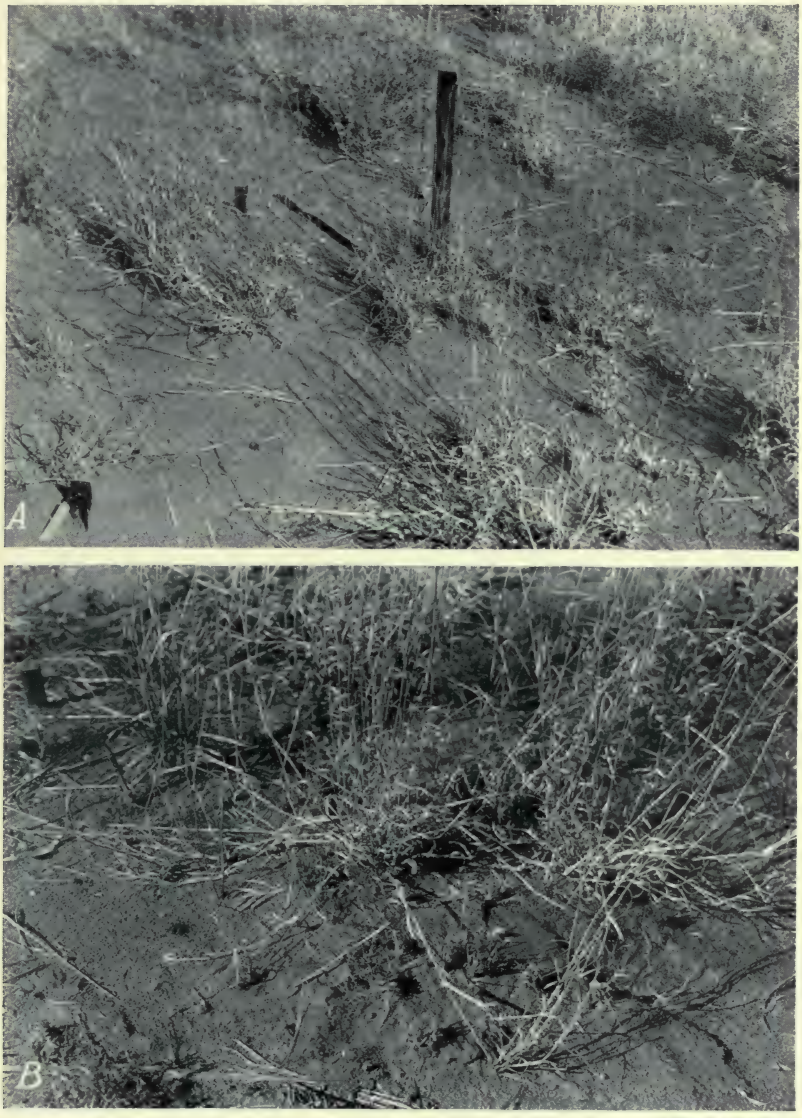
Much depends upon the vigor of the vegetation as a result of growing conditions during the preceding year, particularly the preceding summer and spring.

The influence of the preceding year's precipitation is very evident in the records of change of plant area. An added inch of precipitation during the previous year results in an average increase of plant area of about 37 $cm^2$ per square meter, and if this added inch be concentrated in the previous summer, with a constant precipitation during the rest of the year, the result is an average change of 56 $cm^2$. These findings are of the utmost significance to range management on semidesert ranges where black grama is or should be dominant.

Illustrations of the influence of previous years' precipitation on change in plant area are as follows:

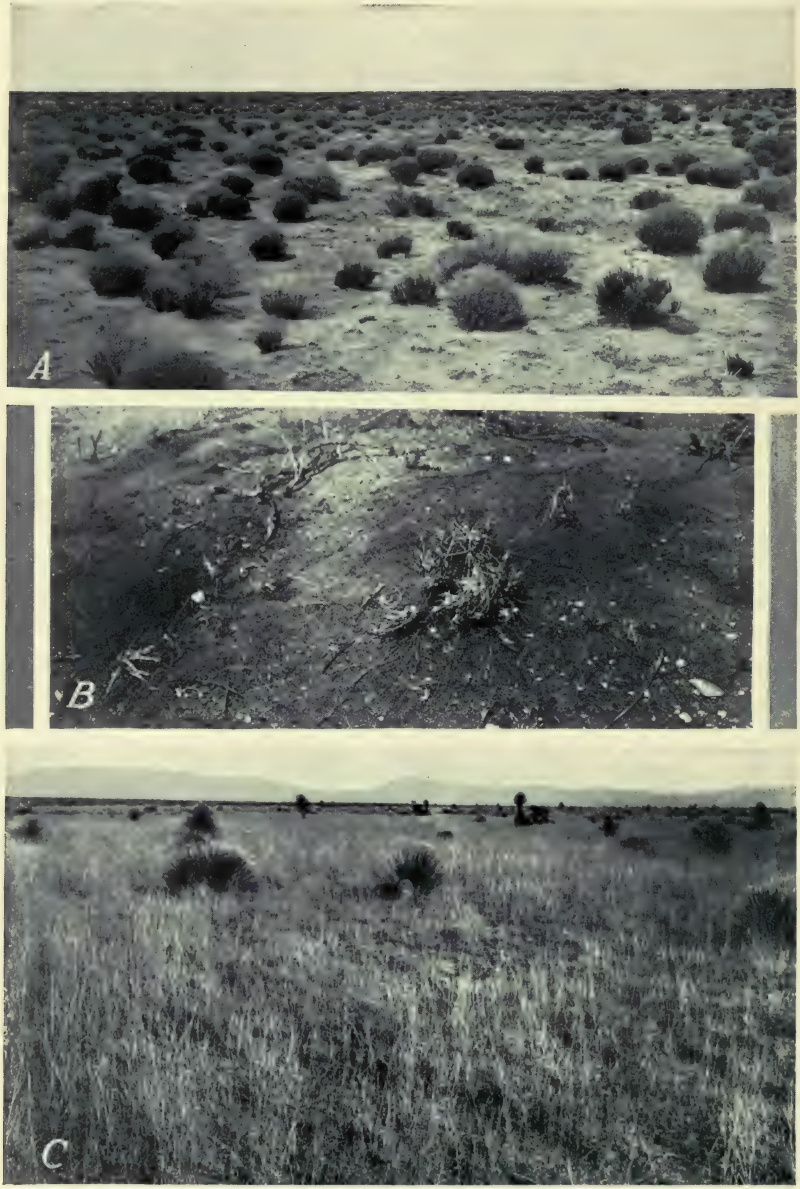
Following a deficiency in rainfall of about 1.9 inches at headquarters in 1916–17, an average decline of about 14 percent in plant cover occurred between the fall of 1916 and that of 1917. This was followed by a further decline in 1918 of nearly 27 percent following the unusual drought of 1917–18. A still further decline of 33 percent after slightly below normal rainfall in 1918–19 reflected a cumulative loss of vigor as the result of drought. Again with only 4.81 inches on the average for the year 1921–22, and unusually scant rainfall after September 1921, an extremely severe decline in plant cover occurred, part of which, however, was due to loss of cover through erosion by wind of the sandy soil from roots and, more particularly, to deposition of wind-blown sand in plant tufts during the spring of 1922. Contrasted to these declines are increases in 1920, 1921, and 1926 following years of above-average precipitation.

There is doubtless a combined effect of inadequate current summer and preceding year's rainfall, especially as indicated by the declines in stand in the years 1917, 1918, 1922, and 1923. In addition to the effect of the extremely high winds and shifting sand in the spring,




F150820 F150819

*A*, Typical stand of black grama grass, showing stem and foliage growth in a favorable summer growing season. *B*, Revegetation of black grama grass by stolons. Note established set at end of stolon in foreground.




F46456A F180815 F150822

*A*, The depletion of black grama grass stands by overgrazing gives aggressive weeds of low forage value, such as snakeweed, the opportunity to take the range. *B*, The last stand of the black grama. As a result of overgrazing the black grama is down to the last plant. Serious wind erosion has removed the soil from around the root crown of the plant and has also exposed the roots. Note very sparse growth of perennial weeds. *C*, Under conservative grazing in normal years a summer forage crop was grown that was heavy enough to insure ample range feed for all but the driest years.

the vigor of the plants was so low and the competition for the inadequate soil moisture of 1922 so great from the heavy stand of black grama attained in 1921 that whole tufts died out. Although the year 1922–23 was only slightly below average in annual rainfall, the dry summer growing season and the extremely low vigor of black grama caused a further decline in 1923.

The favorable influence of high rainfall both in the preceding year and during the current summer is especially shown by the large increase in 1920 and in 1926 as compared to the years immediately preceding. In 1920 the vigor of the vegetation was built up by the good moisture supply of the previous summer, and the copious rainfall which started in May and continued throughout August brought about an excellent gain in plant area.

### NUMBER AND SIZE OF TUFTS

The amount of vegetation on the ground and the number and size of tufts of black grama in relation to available moisture appears to be of importance in maintaining or improving the stand or even in causing a decline in vegetative cover. The material decline in stand between 1921 and 1922, accompanied by the dying out of whole or large parts of tufts, as a result of inadequate moisture to sustain the stand, has already been referred to. In general, favorable rainfall tends to build up larger tufts on ungrazed range, which ordinarily grow together to form a smaller number of tufts on any given area. Upon the gradual depletion of the available soil moisture during a drought, there is first a drying out in the center of the large tufts, which leaves a ring of small tufts on the outside of the dead center. If the drought period continues, the smaller tufts are further depleted and some of them die.

Table 4, presenting the variation in number and size of black grama tufts on several representative areas ungrazed by livestock, shows that there was a breaking up of the large tufts into smaller tufts in the dry year of 1918 and a still further contraction, with general depletion of stand, into 1919. Similarly in 1922 and in 1925, dry years, tufts were smaller than in the years preceding. In years of good rainfall, tufts grew together again, but, as shown by intensive study of plant areas on the ground, the greatest increase took place out from the edge of the original tufts in a direction where there was very little interference from dead crown and root material and less competition by other tufts for available soil moisture. With continued favorable growing conditions, the tuft area increased rapidly. Such coalescing of tufts occurred especially in 1920, 1921, 1924, 1926, and 1927. Figure 2 shows the variation in size and number of tufts as the result of breaking up of tufts and of subsequent expansion of tufts on a representative quadrat. There was a breaking up and increase in number on this quadrat during the dry period from 1916 to 1919, an expansion in size and reduction in number during the favorable conditions from 1919 to 1921, and a severe dying out from extreme drought conditions from 1921 to 1923, followed again by another expansion in size and reduction in number during the period from 1924 to 1926.

TABLE 4.—*Variation in number and size of black grama tufts, exclusive of new stolon areas, on representative ungrazed quadrats* [1]

| Year | Total average area of tufts | Average number of tufts | Average size of tuft | Year | Total average area of tufts | Average number of tufts | Average size of tuft |
|---|---|---|---|---|---|---|---|
| | *Cm²* | *Number* | *Cm²* | | *Cm²* | *Number* | *Cm²* |
| 1916 | 529.0 | 40.0 | 13.2 | 1923 | 29.5 | 9.2 | 3.2 |
| 1917 | 528.5 | 35.5 | 14.9 | 1924 | 104.8 | 6.8 | 15.4 |
| 1918 | 398.5 | 44.0 | 9.1 | 1925 | 78.0 | 10.2 | 7.6 |
| 1919 | 243.2 | 80.8 | 3.0 | 1926 | 228.5 | 9.5 | 24.1 |
| 1920 | 432.0 | 60.5 | 7.1 | 1927 | 211.5 | 8.2 | 25.8 |
| 1921 | 462.2 | 50.2 | 9.2 | | | | |
| 1922 | 51.5 | 14.5 | 3.6 | Average | 294.3 | 31.2 | 9.4 |

[1] Data averaged from 2 quadrats for 1916, 1917, and 1918, and averaged from 4 quadrats for all other years.

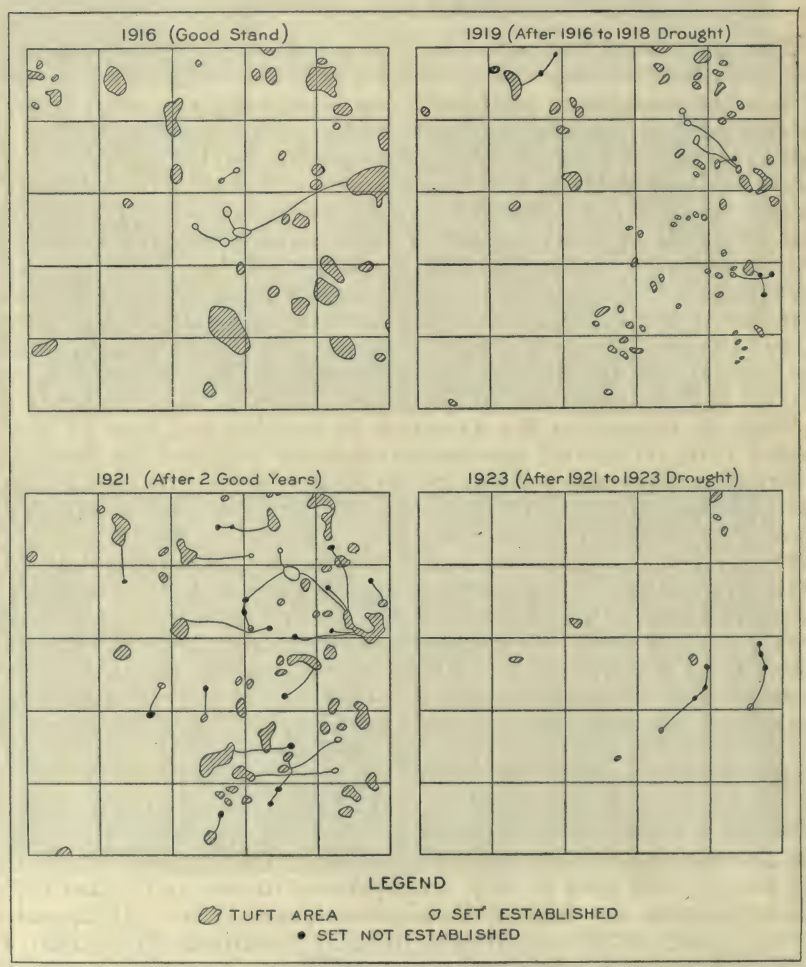



FIGURE 2.—Variation in size and number of black grama tufts on an ungrazed quadrat over an 8-year period.

## PRECIPITATION AND REVEGETATION

Where unfavorable climatic conditions or overgrazing or a combination of the two have destroyed almost completely the stand of native grasses, further usefulness of the range is dependent upon the ability of the remnants of the stand to revegetate. This, in turn, will largely depend upon the influence of rainfall upon the several processes or methods of revegetation of black grama and its associated species.

Table 5 gives the germination percentage of the seeds of black grama and its associates during several years, by laboratory test, together with the growing conditions in the summers the seed was produced. In spite of the extremely low viability of black grama seed as a general rule, a fair amount of viable seed is produced occasionally, as in 1917 and 1923. Observations during the dry years following these seed crops failed to show any black grama seedlings, owing doubtless to the effect of drought at the time of germination. In 1919 when conditions were most favorable for a forage crop little viable seed was produced. Further studies at the Jornada have shown that in some very favorable growing years, when viable black grama seed was produced, seedlings were found the following year.[9] As a general rule, however, a large percentage of the florets fail to develop well-matured seed.

TABLE 5.—*Germination percentages of seed of black grama and associated range grasses under different summer growing conditions, 1917–26* [1]

| Year | Summer growing conditions | Germination | | |
|---|---|---|---|---|
| | | Black grama | Red three-awn | Sand dropseed |
| | | *Percent* | *Percent* | *Percent* |
| 1917 | Poor (droughty) | 27.5 | 40.0 | 2.0 |
| 1919 | Excellent | 10.5 | 82.0 | .0 |
| 1920 | Excellent, but seed maturity poor | 2.0 | 65.0 | .0 |
| 1921 | Fairly good | ---------- | 26.0 | .0 |
| 1922 | Poor (droughty) | 4.0 | 7.0 | .0 |
| 1923 | Fairly good | 40.7 | 90.6 | 3.0 |
| 1924 | Poor | .0 | ---------- | .0 |
| 1925 | Fairly good | 2.0 | 59.0 | 1.0 |
| 1926 | Intermittently good and poor | 2.0 | [2] 17.0<br>55.0 | [2] 42.0<br>75.0 |

[1] Tests for 1917–21 were made by the Bureau of Plant Industry; those for 1922–25 by the New Mexico College of Agriculture and Mechanic Arts; and that for 1926 by Carola V. Jackson, of the University of Chicago.

[2] Two crops were produced in 1926. The hard seed coats of the sand dropseed were pricked to approximate the abrasive action of the wind-blown surface of the sandy soil in which the seed lies dormant during drought. This treatment accounts for the great increase in germination percentage.

Uneven distribution of precipitation during the summer growing season may prevent the maturity of what appears to be the making of a good seed crop. In 1920, for example, favorable growing conditions existed during June, July, and August, and during these months black grama made excellent foliage and flower-stalk growth, but in September the rather scattered light showers that fell allowed the plants to dry up and only a poor seed crop matured. The uneven

[9] CAMPBELL, R. S., and CANFIELD, R. H. ANNUAL REPORT, JORNADA RANGE RESERVE, 1927. (Mimeographed.)

distribution of rainfall in 1926, which resulted in very rapid growth of black grama in May, retardation during June, revival of growth during July, and drying up of the grass during August, greatly interfered with the production of flowers and their fertilization and but little seed was produced that year.

### NATURAL RESEEDING

The production of black grama flower stalks and flowers varies from a luxuriant crop during extremely favorable growing seasons to practically none during drought. However, only a few black grama seedlings in occasional years were observed during the period 1915 to 1927 on the Jornada Experimental Range. This scarcity is doubtless due to the failure of the species to mature its seed satisfactorily and to the poor viability of that seed. Several grass and weed species associated with black grama have considerable advantage over it in the production and viability of seed and establishment of seedlings. Of these species, red three-awn and the sand dropseed grasses are typical. Good seedling stands of the three-awn grasses, the sand dropseed grasses, and numerous weeds became established in the more favorable years, especially in years of above-average precipitation following drought. Red three-awn produces and matures its seed crop earlier in the season and more rapidly than black grama. It matures some viable seed every year regardless of rainfall, and in favorable years yields a large crop generally with a high degree of viability (table 5). In the erratic growing season of 1926 the plants under observation produced two seed crops. An especially good stand of seedlings became established in 1920, following the excellent seed crop of 1919; these increased rapidly in area. Red three-awn is not so long-lived a plant as black grama. It usually lives only 4 or 5 years, and in droughty years, such as 1922, it may be practically killed out. Therefore, only its ability to produce viable seed in abundance and to become reestablished through seedlings enables it to hold its place as an important forage plant.

During favorable summer growing seasons the sand dropseed grasses yield very large crops of seed, and ordinarily some seed is produced every year. Judging by laboratory germination tests made in the years up to 1926 (table 5), it might have been supposed that very little of this seed was viable. In that year, however, Jackson [10] employed a new method in testing this seed. The unusually hard seed coat was pricked or abraded, to approximate the effect of the constant rubbing given dormant seed by wind-blown sand during drought. The results amply confirmed the theory that it is this abrasive action of the sand which enables the seed to germinate when the first favorable growing conditions occur. Further substantiation is found in the fact that in years following drought good stands of sand dropseed seedlings invariably appear, especially in rather loose, exposed sandy areas. Even though there was only a scant stand of plants on the range from 1918 to 1922, inclusive, sufficient seed was available after 2 years of drought to start a stand of seedlings during the short intervals of good precipitation in 1923.

[10] JACKSON, C. V. SEED GERMINATION IN CERTAIN NEW MEXICO RANGE GRASSES. Bot. Gaz. 86: 270–294, illus. 1928.

The climatic conditions of 1926 brought an exceedingly good seedling crop as well as a good seed crop on older plants. These grasses are of importance both as forage and because of their ability to reestablish themselves quickly after a drought. Their exceedingly rapid increase in density aids also in holding the loose, drifting sand, and thus prepares the way for the reestablishment of the slower black grama.

### LATERAL SPREAD BY TILLERING OF BLACK GRAMA TUFTS

Since black grama is so uncertain in its habits of seeding and germination, revegetation by lateral spread and by stolons must be depended on for its maintenance and improvement. The increase in area by lateral spread during a given growing season depends chiefly upon the vigor built up in the preceding year from favorable climatic conditions. It is also dependent upon the intensity of grazing and the density of the vegetation. In favorable growing years the increase in area by this method may be nearly 200 percent if the stand is thin at the start.

In 4 different years from 1915 to 1927, as shown in table 4, the black grama range was improved through lateral spread of the tufts. Marked increases resulted in 1920 and 1926 as compared to the preceding year from the increased plant vigor built up by the favorable precipitation of the preceding growth year and favorable growing conditions in the current summer. A small increase was shown in 1921 even with subnormal summer rainfall that year, doubtless as a result of the accumulated vigor from the favorable conditions of the 2 preceding growth years. From the very low plant areas of 1923 there was a fairly high percentage increase in 1924, possibly owing to the ability of the scant stand of vegetation to make effective use of available rainfall during this period, even though this was average or below. In general, the rainfall in other years was insufficient to bring about any noticeable spread of tufts.

A study of the records of individual quadrats indicates that the percentage of increase by lateral spread was influenced by the stand of black grama at the beginning of each period of increase. The greatest increases occurred on the quadrats of least area. Probably there was a greater supply of soil moisture available for each individual plant tuft. Thus, on two quadrats, the area of black grama varied from 192 to 194 $cm^2$ in 1919 and showed an average increase by tillering of 129 percent in 1921. Two others, which in 1919 had the greatest area of black grama (266 and 321 $cm^2$), increased only 64 percent in the same period. Again, in 1925, the area of black grama declined to an average of 44 $cm^2$ on two low-density quadrats. By the close of the 1926 season these two showed an average increase of 267 percent. The other two quadrats, with 82 and 141 $cm^2$ in 1925, had increased only 163 percent by the fall of 1926. In none of these cases did a high-density quadrat have as great an increase as a low-density quadrat.

### REVEGETATION BY STOLONS FROM OLD TUFTS

The other important method of natural reproduction or revegetation of black grama is by stolons. The record of average produc-

tion of stolons and the establishment and maintenance of sets for representative areas from 1915 to 1927 is shown in table 6.

TABLE 6.—*Revegetation by stolons of black grama on ungrazed areas*

| Year | Average on ungrazed quadrats | | | | Year | Average on ungrazed quadrats | | | |
|---|---|---|---|---|---|---|---|---|---|
| | New stolons | Rooted sets present | Area of sets | Area increased | | New stolons | Rooted sets present | Area of sets | Area increased |
| | *Number* | *Number* | *Cm²* | *Cm²* | | *Number* | *Number* | *Cm²* | *Cm²* |
| 1915 | 6.0 | 9.0 | 27.0 | | 1923 | 0.8 | 0.2 | 0.8 | (1) |
| 1916 | 2.0 | 8.0 | 21.5 | (1) | 1924 | .8 | 1.0 | 3.0 | 2.2 |
| 1917 | 3.5 | 9.5 | 32.0 | 10.5 | 1925 | 9.0 | 6.2 | 11.2 | 8.2 |
| 1918 | 11.0 | 5.5 | 15.5 | (1) | 1926 | 26.2 | 22.0 | 78.5 | 67.3 |
| 1919 | 8.0 | 3.5 | 8.5 | (1) | 1927 | 17.8 | 17.8 | 91.8 | 13.3 |
| 1920 | 31.8 | 22.2 | 42.0 | 33.5 | | | | | |
| 1921 | 18.8 | 14.2 | 52.0 | 10.0 | Average | 10.7 | 9.3 | 29.7 | |
| 1922 | 2.8 | 1.5 | 2.8 | (1) | | | | | |

[1] Decrease in area.

The production of flower stalks or culms that eventually become stolons is largely limited to years of average or better than average rainfall, although a small number may be produced in seasons of below-average precipitation. Ordinarily, the year of favorable growing conditions required for new sets to be produced must be followed by another favorable year for the sets to become rooted. For example, in 1919 an excellent crop of flower stalks was produced, some of which bent over sufficiently to become stolons, and a large number of unrooted sets developed at the nodes. Of these a relatively small number, mostly near the ends of the stolons, became rooted that season. During 1920, which also was a favorable year, the formation of stolons continued and, owing to the increased weight of new foliage growth at each unrooted set, many of both years' sets took root and became established. An occasional 1920 flower stalk also became a stolon. Some of the 1920 sets succumbed in 1921 because of poor root systems or competition from plants, but other sets became better established and increased slightly in area. Another excellent crop of stolons was produced in 1926 in spite of a very small number of old tufts; and 1927 was also favorable for the production and establishment of new sets. The greater increase in area of established sets in 1926 and 1927 as compared to 1920 and 1921 was probably the result of less interference from a greatly depleted stand of old tufts.

Apparently rainfall did not influence the manner in which the stolons either extended out radially from the base of the tuft along the surface of the ground or bent over from different parts of the tuft as shown in figure 3. However, the variation in the length of the stolons—from 10 to 50 cm—depends largely upon rainfall.

The number of stolons per tuft varies from 1 to 9, and there appears to be no relationship between the size of a black grama tuft and the number of stolons produced. It is further apparent that a high density of black grama is not necessary for the formation of a large number of stolons and establishment of sets; for example, a good number of stolons were produced and sets established with a relatively low density in 1926 and 1927.

Measurements made on one large tuft in 1920 indicate that up to a certain point the number of established sets increases with the distance from the parent tuft. Six percent of the established sets were within a distance of 7 cm of the tuft, 28 percent were 7 to 10 cm from the tuft, 58 percent 10 to 20 cm, and 8 percent beyond 20 cm. Further checks of other tufts indicated that similar percentages would generally hold true.

Old black grama tufts competed somewhat with the new sets, but the competition was not serious enough, with the stand present during the period of the study, to retard the increase of the established new sets by lateral spread, except in the drier years. In a large number of instances the old tuft and the new plants from stolons grew together and formed a large irregular tuft. As shown in fig-

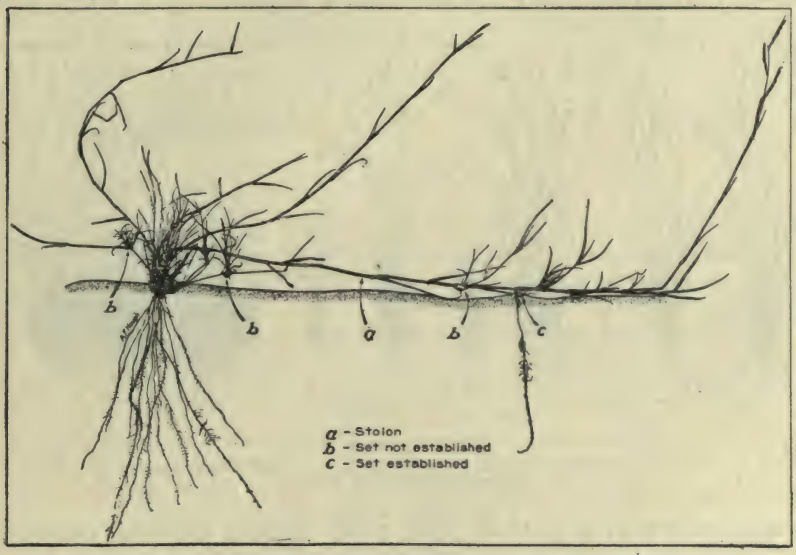



FIGURE 3.—Method of revegetation of black grama by stolons.

ure 4 some established new plants eventually have a greater area than the original parent tuft. Generally such sets are established a sufficient distance from the old tufts to enable them to spread rapidly without much competition from the older plants.

The manner in which the disastrous effect of drought on the maintenance of new plants established from stolons is aggravated when tufts are many and density is high is clearly indicated by the heavy mortality during the winter, spring, and summer of 1922. Only a few sets survived the drought which began in 1921 and ended in 1925. Some of the survivors, however, produced stolons in 1926 and 1927 from which new plants originated.

This method of revegetation is chiefly of value in that it makes it possible for black grama to establish new plants at some distance from old established tufts, with the result that the increase in area is greater than would be possible from lateral spread of old tufts alone.

## INFLUENCE OF GRAZING INTENSITY ON BLACK GRAMA

In order to determine the degree of utilization of black grama range that will give the best economic use and at the same time perpetuate the range, it is important to consider the specific influence of different degrees of use upon black grama and its important associated species. This is even more necessary in years of drought when area of black grama may fall as low as 10 or 11 percent of the maximum stand, and 20 percent of the average over a 13-year period, and when volume of growth may also be seriously reduced.

In earlier investigations on the Jornada, Jardine and Hurtt[11] compared conditions on the experimental range conservatively grazed for several years with those on unfenced public range, originally similar in character, and found on the uncontrolled range that serious overgrazing had extended to a distance of 4 miles from

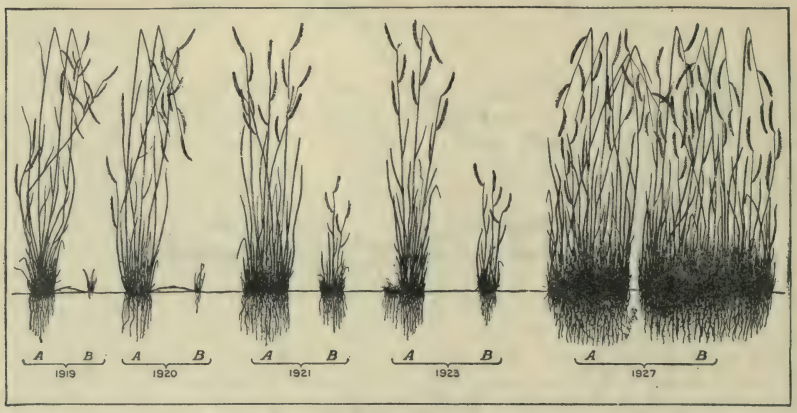



FIGURE 4.—Progress of revegetation by stolons: *A*, original black grama tuft; *B*, black grama plant from stolon.

permanent watering places. The study showed that the combined area of black grama, three-awn, and sand dropseed grasses at one half mile from watering places on the experimental range was equal to that approximately 4½ miles out from water on the unfenced range. Beyond these respective distances there were no differences in plant area. On the outside range black grama alone failed perceptibly within 3¾ miles of water and was gone completely within one half mile. At 1 to 2 miles on the open range the plant area was not over one third of the normal area on the experimental range.

Jardine and Forsling[12] found that black grama, where it was being seriously overgrazed, declined in area in time of drought to 18 percent of the area on similar ungrazed range, implying an extreme shortage in the forage crop. They found the grazing capacity of the overgrazed range prior to drought to be approximately 82 percent of that of similar fenced range that had been lightly grazed during the summer and slightly undergrazed for the year as a whole during

[11] JARDINE, J. T., and HURTT, L.C. INCREASED CATTLE PRODUCTION ON SOUTHWESTERN RANGES. U.S. Dept. Agr. Bull. 588, 32 pp., illus. 1917.
[12] JARDINE, J. T., and FORSLING, C. L. See footnote 7, p. 10.

a period of 3 years. During drought the overgrazed range declined in grazing capacity to 51 percent of the similar fenced range. In addition to the reduction in grazing capacity on the overgrazed range, the shortage of forage resulted in excessive losses of livestock from starvation, in the stunting of young animals, and in greatly reduced calf crops.

### INFLUENCE OF CONSERVATIVE GRAZING

The results obtained over the 13-year period from 1915 to 1927 indicate clearly that forage production on black grama range may be maintained under conservative grazing as well as or better than under complete protection from grazing (pl. 2, *C*). In dry years the range feed on many of the conservatively grazed areas was utilized to the point of slight overgrazing but in years with average or better growing conditions utilization by the end of the grazing year seldom exceeded 80 to 85 percent of the black grama foliage produced each year. Under these conditions the grass stand held up as well as or better than on the ungrazed check areas where weather alone was the chief influencing factor.

### HEIGHT GROWTH

The height growth of black grama under conservative grazing averaged 34.7 cm (13.7 inches) from 1919 to 1927, inclusive—only slightly less than the average of 37 cm (14.6 inches) on ungrazed areas for the same period. As shown in table 7, this average relationship is generally typical. The considerably lower heights in the dry years of 1922 and 1924 are probably due to the fact that the use of the range in these years amounted to a slight overgrazing. There was, however, no sustained effect of the heavy grazing in these bad years.

TABLE 7.—*Average height of black grama stems under conservative grazing and on ungrazed range*

| Year | No grazing | Conservative grazing | Year | No grazing | Conservative grazing | Year | No grazing | Conservative grazing |
|---|---|---|---|---|---|---|---|---|
| | *Cm* | *Cm* | | *Cm* | *Cm* | | *Cm* | *Cm* |
| 1919 | 42.7 | 40.1 | 1923 | 28.0 | 33.7 | 1927 | 38.0 | 36.4 |
| 1920 | 50.3 | 47.9 | 1924 | 31.7 | 21.9 | | | |
| 921 | 30.3 | 28.5 | 1925 | 33.3 | 40.3 | Average | 37.0 | 34.7 |
| 1922 | 28.3 | 16.6 | 1926 | 50.0 | 46.9 | | | |

### PLANT AREA

In most years, as shown in table 8, there was little difference between the yearly fluctuations in plant area on conservatively grazed range and on ungrazed range—the years 1918, 1922, 1923, and 1924 being the notable exceptions. The stand of black grama on the conservatively grazed range never reached as great an average area in the maximum years as on the ungrazed range nor dropped so low when the effects of drought were most severe. For the 13 years as a whole the average density of black grama was practically the same

on conservatively grazed range as on the ungrazed range. The extreme dry weather in the winter, spring, and summer of 1922 that caused a severe decline on the ungrazed range had less effect on the grazed range except for several localities that had unusually heavy stands of black grama. In the fall of that year the grazed exceeded the ungrazed range in area of black grama by 38 percent. From then until 1927 the black grama on the conservatively grazed range was more vigorous and the stand was maintained at a higher point. Rapid improvement was evident during 1926 and 1927 under very light grazing.

TABLE 8.—*Average plant area of black grama on conservatively grazed and ungrazed areas, 1915–27*

| Year | On ungrazed range | On conservatively grazed range | | Year | On ungrazed range | On conservatively grazed range | |
|---|---|---|---|---|---|---|---|
| | | Area | Comparison with ungrazed range | | | Area | Comparison with ungrazed range |
| | *Cm²* | *Cm²* | *Percent* | | *Cm²* | *Cm²* | *Percent* |
| 1915 | 548.2 | 507.0 | 92.5 | 1923 | 60.0 | 156.6 | 261.0 |
| 1916 | 537.1 | 494.6 | 92.1 | 1924 | 125.7 | 198.8 | 158.2 |
| 1917 | 461.7 | 387.5 | 83.9 | 1925 | 106.7 | 150.4 | 141.0 |
| 1918 | 337.4 | 213.0 | 63.1 | 1926 | 283.4 | 336.5 | 118.7 |
| 1919 | 227.4 | 194.6 | 85.6 | 1927 | 277.9 | 475.2 | 171.0 |
| 1920 | 433.4 | 365.8 | 84.4 | | | | |
| 1921 | 534.3 | 435.9 | 81.6 | Average | 310.8 | 312.6 | 100.6 |
| 1922 | 107.6 | 148.2 | 137.7 | | | | |

REVEGETATION BY NATURAL RESEEDING, LATERAL SPREAD, AND STOLONS

The failure of black grama to reseed naturally under conservative grazing could hardly be attributed to this use of the range, since in favorable growing seasons the production of flower stalks was not materially hindered thereby. Failure was due rather to the inability of black grama, even on ungrazed range, to mature seed, as well as to the poor viability of the seed.

Natural revegetation by lateral spread was the most effective means of increasing the area of black grama on the conservatively grazed range. There were three 2-year periods of increase in area by lateral spread, culminating, respectively, in 1921, 1924, and 1927, and these corresponded essentially to similar increases on ungrazed range except that the black grama stand on the ungrazed range decreased slightly in 1923 and 1927. This indicates that as rapid recovery from drought may be expected under conservative grazing as under no grazing.

In general, revegetation by stolons was not as effective on grazed as upon ungrazed land, either in good years or poor years, but, nevertheless, it remains an important means of restoring, in favorable growing years, the stands that have become depleted by drought, and thereby of increasing the black grama on conservatively grazed ranges, as is shown in figure 5.

Under conservative grazing some flower stalks remained to become stolons. Likewise the new sets that developed on the stolons eventually became firmly established and in favorable years made suffi-

cient foliage growth to develop the vigor of the new plants and later to increase materially in area. As has been previously shown, drought seriously affects the newly established sets on all areas, but it is very evident that conservative grazing, although it somewhat hinders revegetation by stolons, will, nevertheless, permit the building up of a depleted stand in favorable growing years.

### HEAVY OVERGRAZING YEAR AFTER YEAR

The effect of heavy overgrazing year after year upon the stand of black grama was fivefold: (1) The existing stand of black grama rapidly broke down and eventually died; (2) natural revegetation was seriously handicapped and reduced because of the low density and poor vigor of the old plants and excessive trampling of new plants; (3) drought losses were intensified; (4) competition from inferior perennial grasses and weeds increased; and (5) a marked reduction appeared in the annual forage crop. The effects of such a grazing practice on livestock production are evidenced in a reduced grazing capacity of the range and the poor condition of the livestock, which in turn seriously reduce the calf crop, increase

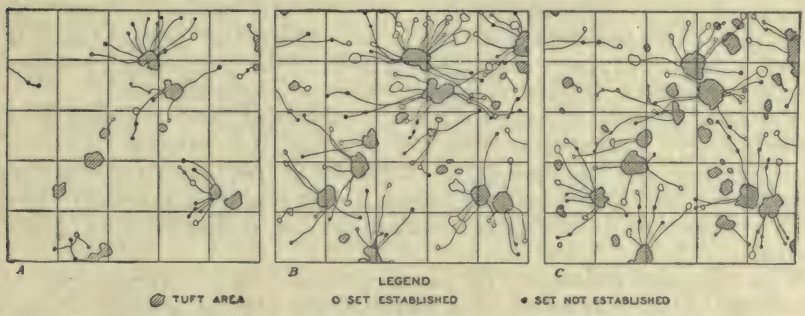



FIGURE 5.—Revegetation of black gama by stolons on a conservatively grazed range on quadrat N 6; *A*, 1925; *B*, 1926; *C*, 1927.

losses from starvation, and allow no provision for reserve feed in critical drought periods.

The average height growth of black grama was very much reduced by continued heavy overgrazing. In dry years it did not exceed 20 percent of the height growth on the ungrazed range, and in more favorable years it was barely 75 percent. Furthermore, in drought years, the forage crop is often completely utilized shortly after the close of the summer growing season.

The effect of heavy overgrazing year after year on the stand of black grama is shown in plate 2, *A* and *B*. In 1915, following several years of favorable growing conditions, black grama on continuously overgrazed range occupied an average of but 154 cm² per square meter, only 28 percent of that on ungrazed range and 30 percent of that on conservatively grazed range in that year. At the end of the severe drought in 1918 the area of black grama had declined to 30 cm² per square meter, 9 percent of that on ungrazed range. As a consequence of the second drought, the greatest influence of which was felt, on the overgrazed range, in 1922, the area again declined to 25 cm², 23 percent of that on the ungrazed range

in that year. In the drought period up to 1924 black grama was completely killed out on a large number of range areas and was brought to an extremely low density on others. In favorable climatic years there was not much opportunity for improvement in stand on ranges that were constantly being overgrazed. The small number of tufts that remained after a drought were usually impaired in vigor.

When the range is heavily overgrazed, the improvement of black grama stands by natural revegetation is greatly hindered. The total plant cover becomes so depleted that the loose sandy surface soil is readily exposed and therefore is subjected to wind erosion. It becomes increasingly difficult for black grama to reestablish itself in the presence of this unstable soil condition.

The vigor of the old black grama plants becomes impaired so that increase by lateral spread of the tufts by tillering is hindered even in the more favorable years. The production of stolons is rather limited because of the poor production of flower stalks and their constant grazing by livestock. The establishment of new plants by stolons is slow and uncertain even in the more favorable years because of excessive trampling of the range. In most instances plants newly established in one year are trampled out by livestock later in the same year or in the following year. Once the stand is destroyed, poor seeding habits of black grama make it practically impossible for the species to become reestablished.

The loss in stand from drought is intensified by continued heavy overgrazing. Under conservative grazing the average stand of black grama was reduced by drought to 29 percent of its average maximum. On the overgrazed range, however, the stand was reduced to 5 percent of the average maximum on conservatively grazed range.

The extreme depletion of black grama under overgrazing encouraged the development of a stand of the less palatable perennial sand dropseed grasses because of their more aggressive seeding habits and their ability to increase rapidly in density when more moderately grazed in favorable years after the establishment of the new plants. When heavily grazed in dry years they produce poor seed crops, but in the more favorable growing years yield fair crops of seed which, under favorable conditions, later germinate and become established seedlings. In drought periods the area of these grasses may be severely affected, as in 1918 when it dropped to an average of 18 $cm^2$ per square meter, 18 percent of the 1915 density. Later, following two favorable growing seasons of 1919 and 1920, it increased to 63 $cm^2$ but again dropped to 16 $cm^2$ in 1922. Dropseed grasses are gradually replacing the black grama grass on many overgrazed ranges in southern New Mexico, chiefly because of their reseeding ability.

#### FULL USE OF FORAGE IN GOOD YEARS AND SLIGHT OVERGRAZING IN DRY YEARS

The combination of full use of forage in good years and slight overgrazing in years of poor forage growth did not permit the full recovery of black grama from the losses suffered in drought years. The average area of black grama under such grazing during the

13-year period was approximately 71 percent of that under both conservative grazing and no grazing. Starting in with an average area of 335 $cm^2$ per square meter there was a decline to 152 $cm^2$ by 1919, a recovery to 322 $cm^2$ in 1921, and a new decline to 112 and 105 $cm^2$, respectively, in 1922 and 1923. Then after a recovery to 152 $cm^2$ in 1924 it declined again to 115 $cm^2$ in 1925. Thus the slight overgrazing in each drought period caused an important decline, giving an area of 50 to 75 percent of that under conservative grazing in the same years, although greater than that which prevailed without grazing in the general drought period from 1922 to 1925. The stand on the average remained fairly vigorous and in a condition to respond quickly to lighter grazing in the more favorable years. This is especially noticeable in the recovery under light grazing between 1925 and 1927 when the quadrats used to represent full use of forage in good years and slight overgrazing in dry years up to 1925 reached an average area of 391 $cm^2$. The lateral spread of the tufts by tillering in the favorable growing years, however, was not as effective as on the ungrazed or conservatively grazed ranges.

Average height growth of black grama in favorable growing years was only slightly under that of the ungrazed range, but in dry years it was much less than that on ungrazed range, as for example in 1922 when it was only 53 percent.

The stands of the sand dropseed and three-awn grasses on the average under full use in good years and slight overgrazing in dry years were generally very low in density, only in a few instances exceeding black grama and at no time attaining a sufficient density to hinder the growth of black grama. The stands of these grasses decreased greatly in drought periods and in fact on some areas went out completely. They came back in a very small degree in 1919 to 1921, but in many instances only to succumb again in the following drought period. They were given a good opportunity, however, following the depletion of the black grama stand in that drought period, to increase in density by natural reseeding. For example, on range near the headquarters and West Well, the sand dropseed grasses had declined to their low average of 16 $cm^2$ per square meter by 1922. The black grama stand was at its low of 105 $cm^2$ in 1923. By 1927 the sand dropseed grasses occurred in some abundance, an average of 152 $cm^2$ per square meter. This did not, however, prevent a material increase in black grama by lateral spread and stolons, under light grazing from 1925 to 1927, and therefore black grama with an average of 391 $cm^2$ still remained the dominant grass in 1927 on all of the quadrats except one. Where a stand of black grama was maintained at a moderate density in drought periods it increased in favorable years to such an extent that the sand dropseed grasses were not able to develop materially. This was especially evident on the South Well area where the stand of black grama, even though greatly depleted by the drought that started in 1922, built up so rapidly by lateral spread and stolons when rainfall improved that the stand of sand dropseed grasses in this area, not producing good crops of seed, became established much slower and in less density than on any of the other range areas.

Slight overgrazing in years of short feed production is detrimental to stands of black grama because it hinders this species from attaining its optimum condition. The uncertain rainfall in southern New Mexico further complicates the situation under such utilization.

#### OVERGRAZING DURING THE SUMMER GROWING SEASON

The study of the effects of overgrazing in summer only was made (1919–25) on range consisting principally of summer forage grasses on which there were small isolated black grama areas. Because of the high palatability and low density of the black grama, the abundance of summer grasses did not prevent the overgrazing and rapid breaking down of the stand of black grama.

Summer overgrazing reduced the height growth of black grama even in favorable growing seasons, but not so severely as did heavy year-long overgrazing. The maximum height growth attained in such a favorable growing season as that of 1920 was 66 percent of that on conservatively grazed range. In the drought year of 1922, local showers in the summer growing season were responsible for a better average height growth on the summer-overgrazed quadrats than on the other grazed areas.

The average area of black grama in 1919 on the quadrats subsequently overgrazed each summer was 225 $cm^2$, practically the same as that of the ungrazed range and 16 percent better than that on the quadrats representative of the range conservatively grazed throughout the entire period of the study. The total increase in density in 1920 and 1921 was 28 percent as compared to 124 percent on conservatively grazed range and 135 percent on ungrazed range. In the drought that followed, the stand of black grama on the summer-grazed range dropped in 1923 to 44 $cm^2$ or 15.4 percent of its 1921 density. A slight improvement occurred in 1924 and 1925 when the overgrazing in summer was not quite so severe.

The opportunities for natural revegetation of the stand of black grama in the favorable growing seasons were greatly impaired by the constant close cropping which the species suffered, which largely prevented both the lateral spread of the tufts by tillering and the establishment of new plants by stolons. Furthermore, the vigor of the individual plants was seriously depleted by the severe grazing, especially during drought.

The stand of sand dropseed grasses which occurred with the black grama on the isolated sandy areas was extremely low throughout the period under study and consequently was not considered a serious factor in competition with the black grama.

Summer overgrazing was chiefly responsible for the breakdown in the stand of black grama during drought periods and interfered materially with its improvement by natural revegetation in favorable growing seasons. While such overgrazing cannot entirely be avoided on the isolated black grama areas in the summer when the bulk of the feed can best be utilized, it is well to discourage use of the black grama as much as possible by judicious salting of those large areas supporting the other vegetation best suited for summer use.

## SUMMARY

Black grama, the subject of this 13-year study on the Jornada Experimental Range in southern New Mexico, owes its great value in this region of low, uneven rainfall, high temperatures, high evaporation, and relatively severe winds, to its characteristically drought-resistant quality and its high palatability and forage value both in summer and winter. The main growth of black grama is made during the summer rainy season, ordinarily July, August, and September. Only under the most favorable precipitation is growth made in the spring. Black grama seldom reproduces from seed but, after drought or overgrazing, revegetates rapidly from residual plants by tillering and by stolons.

The period of study included two droughts, one of which continued through 1916, 1917, and 1918, and a second which began in the late summer of 1921 and continued almost 5 years until the spring of 1926. In addition to observation of the effects of variations in seasonal and annual precipitation, the areas studied were submitted to several intensities of grazing use.

The area of black grama on ungrazed range, both in pure stands and in association with other perennial grasses, gradually declined during the first drought, following a marked and consistent lag, to a point 41.5 percent of the original stand at the beginning of the study; practically recovered to the original area again as the result of 2 favorable growing years; then dropped very suddenly in the following 2 years of drought to the extremely low point of 10.9 percent of the original area and 19.3 percent of the 13-year average; remained low for the rest of the drought period; and finally increased markedly during the succeeding favorable years. The increase or decrease in the area of black grama from one fall to the next is influenced mainly by the vigor of the plants at the start of the current growing season, as reflected by the previous year's or even by the previous summer's precipitation. Current summer-seasonal rainfall has no significant effect on the current change in plant density. Ordinarily one favorable growing season appeared to be necessary to restore the vigor of weakened plants before marked improvement in the stand began. On the other hand, it is the rainfall during the current summer season which largely determines the height growth during that season on the existing black grama stands.

The average density of black grama over the 13-year period was practically the same under conservative grazing as under no grazing. The decline during drought was rather similar under both conditions, but the return of favorable rainfall brought more rapid recovery under conservative grazing. Conservative grazing appears to break up the large, separated tufts formed under freedom from use into smaller tufts better adapted to make efficient use of the available soil moisture. Under conservative grazing, other things being equal, natural revegetation of black grama tufts by tillering is far superior to that by stolons, since many of the stolons are removed by grazing; but the latter method is an important means of reestablishing a stand after drought on conservatively grazed range. By means of these methods of revegetation, black grama remains dominant after drought in spite of the rapid inroads of associated grass and weed species.

A grazing practice which involves the full use of black grama range in good years and slight overgrazing in years of short feed gives results considerably below those of consistently conservative grazing. It prevents the maximum development of the black grama stand and permits the inferior associated grasses and other species to secure a foothold on the more depleted black grama areas.

The system of overgrazing in the summer growing season only, year after year, decreases the density of black grama rapidly in dry years and greatly handicaps recovery through natural revegetation in favorable growing periods.

Under heavy overgrazing year after year the density of black grama is apt to decline in drought years to almost a negligible quantity. Such grazing results in unstable soil conditions, greatly weakens individual black grama plants, hampers the recovery of black grama by natural revegetation in favorable years, permits inferior plants to encroach and establish themselves, intensifies the influence of drought, greatly reduces the grazing capacity, and, finally, adds greatly to the instability of production of livestock on the range.

The results of all tests made bring out especially the amazing ability of black grama to survive drought, to recover after a drought period, to compete successfully with associated species, and to remain as the dominant plant on conservatively grazed range in spite of encroachment of sand dropseed and three-awn grasses and other species following depletion of stand by drought. The ability of black grama to withstand conservative utilization by livestock, without a reduction in stand except the variations due to vicissitudes of climate suggests conservative grazing as the most stable and productive system of grazing. Heavier grazing use, in the degree of its intensity, results in gradual or extreme deterioration, a subordinate stand of black grama, reduced grazing capacity, and unsatisfactory conditions for permanent livestock production.

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# PROPERTIES OF WHITE FIR AND THEIR RELATION TO THE MANUFACTURE AND USES OF THE WOOD

By

R. P. A. JOHNSON
Engineer, Forest Products Laboratory

and

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Associate Forester, California Forest Experiment Station
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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D. C.

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UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

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By R. P. A. JOHNSON,[1] *engineer, Forest Products Laboratory,*[2] and M. R. BRUNDAGE, *associate forester, California Forest Experiment Station*[2] *Branch of Research, Forest Service*

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## INTRODUCTION

White fir lumber, a relatively new wood from western United States, is now found quite generally in eastern and middle-western markets. Its introduction into these markets has been in the form of common

[1] Acknowledgment is made of assistance received from many members of the Forest Service, especially to E. M. Davis, Forest Products Laboratory, for the detailed information on characteristic defects of white fir, and to M. I. Bradner, Forest Region 1, for the information on white fir from Idaho. Further acknowledgment is made to the Mountain Pine Sales Association for contributed photographs.

[2] The Forest Products Laboratory is maintained by the U.S. Department of Agriculture at Madison, Wis., in cooperation with the University of Wisconsin; the California Forest Experiment Station at Berkeley, Calif., in cooperation with the University of California.

boards and dimension. A number of questions immediately arise with the entrance of a little-known wood into the lumber markets. The consumer quite naturally wants to know how the new wood compares with woods with which he is familiar. White fir is no exception to the rule, and there is a demand for information on the properties, the adaptability, and the suitability of the wood for various uses, especially small-house construction.

The purpose of this bulletin is to furnish detailed information on the properties and characteristics of the wood of white fir, for the assistance of consumers and manufacturers in determining the suitability of this wood for specific uses.

The name "white fir" is applied to lumber of several species of true firs.[3] About seven eighths of the lumber marketed as white fir, however, comes from two species, and all but a small percentage of the total is produced in California and Idaho. These two species are lowland white fir (*Abies grandis*), cut chiefly in the "Inland Empire"[4] and redwood region of California, and white fir (*A. concolor*) cut mainly in the Sierras of California. This bulletin deals primarily with the properies and uses of wood of these two species.

The confusion caused by the use of the name "white fir" for other true firs cannot be eliminated entirely, for it is not always possible to segregate by species combined data on the true firs. The following nomenclature is used in the text of this bulletin to eliminate insofar as possible the confusion of species names:

True firs: The tree or lumber of all *Abies* species collectively.

Western true firs: The tree or lumber of all *Abies* species growing in the western United States considered collectively.

Eastern true firs: The tree or lumber of all *Abies* species growing in the eastern United States; namely, balsam fir and southern balsam fir.

Commercial white fir: Collective name for the lumber of a group which may include any of the commercial species of western true firs.

White fir: The tree, timber, or lumber of white fir (*Abies concolor*) and lowland white fir (*A. grandis*) considered together.

White fir (*Abies concolor*): The tree or lumber of the species white fir (*A. concolor*) by itself.

Lowland white fir: The tree or lumber of the species lowland white fir (*A. grandis*) by itself.

The figures in this bulletin showing mechanical and other properties of wood are based on material carefully identified as to species and the names are those used by the Forest Service[5] for the trees from which material was cut.

## SILVICULTURAL IMPORTANCE

### LUMBER CUT

The Bureau of the Census (*27*) reports the 1929 lumber cut of western true firs as 307,000,000 board feet. This includes the cut of five species—white fir (*Abies concolor*), lowland white fir, silver fir, Cali-

[3] The true firs belong to the genus *Abies* as contrasted with Douglas fir, which is not a fir and belongs to the genus *Pseudotsuga*. The common names of the true firs are: Southern balsam fir, balsam fir, Alpine fir, corkbark fir, lowland white fir, white fir, silver fir, noble fir, California red fir, and bristlecone fir.

[4] Northwestern Montana, Idaho north of the Salmon River, Washington east of the Cascade Mountains, and the northeastern tip of Oregon.

[5] The names employed by the Forest Service (*21*)[6] for lumber and for trees from which it is cut are used throughout this bulletin.

[6] Italic numbers in parentheses refer to Literature Cited, p. 75.

fornia red fir, and alpine fir, and is slightly more than 1 percent of the total softwood lumber cut. The annual lumber cut of the western true firs has remained approximately constant since 1922, averaging about 314,000,000 board feet (fig. 1). About two thirds of the lumber cut of the western true firs comes from California, about one fourth from Idaho, and the small remainder is principally from Washington, Oregon, and New Mexico (fig. 2, *A*).

Table 1 shows by States the total, average, and percentage cut of the western true firs for the years 1927, 1928, and 1929. These values differ from those in figure 2, which is based on a 5-year average. Figure 2 shows that the cut of the true firs by States is not in proportion to the stand, consequently it is to be expected that the States other than California and Idaho will eventually produce an increased percentage of true fir lumber and the percentage of cut and stand will be more nearly equalized.

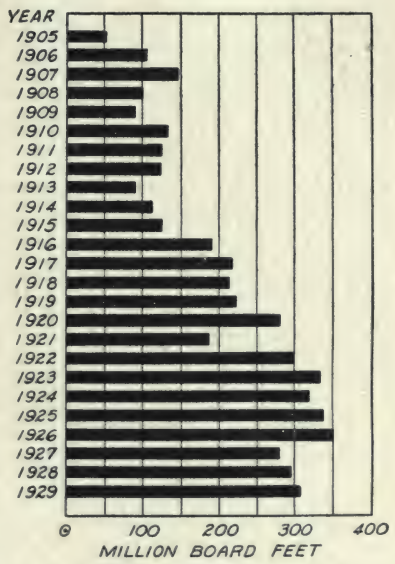


FIGURE 1.—The cut of western true firs by years. It includes some species not generally sold as white fir. No data by species are available but it is estimated that over 95 percent of the cut is from white fir (*Abies concolor*) and lowland white fir.

TABLE 1.—*Average and percentage cut by States of the western true firs, 1927–29*

| State | Average cut, 1927–29 | Percentage of total, 1927–29 | State | Average cut, 1927–29 | Percentage of total, 1927–29 |
|---|---|---|---|---|---|
| | *Board feet* | | | *Board feet* | |
| Arizona | 42,000 | (1) | Oregon | 15,813,000 | 5.4 |
| California and Nevada | 173,436,000 | 59.2 | Utah | 373,000 | 0.1 |
| Colorado | 1,407,000 | 0.5 | Washington | 22,869,000 | 7.8 |
| Idaho | 73,099,000 | 25.0 | Wyoming | 55,000 | (1) |
| Montana | 434,000 | 0.1 | | | |
| New Mexico | 5,493,000 | 1.9 | Total | 293,021,000 | 100.00 |

[1] Less than 0.1 percent.

About 90 percent of all the true fir lumber cut in California is white fir (*Abies concolor*). About 9 percent is lowland white fir and about 1 percent is California red fir. The lumber from Idaho sold as white fir is a mixture of several species, lowland white fir predominating. Occasionally a small amount of alpine fir is included.

### WHITE FIR FORESTS

The stand of western true firs (p. 2) in 1931 is approximately as shown in table 2. The botanical ranges of white fir (*Abies concolor*) and lowland white fir are shown in figure 3. The limits of the ranges shown on the map in figure 3 represent the entire known spread of

each species irrespective of whether or not it occurs in commercial size or commercial quantities. Probably less than half of the total stand is considered as commercial by lumbermen at the present time, the limiting factors being ease of accessibility and percentage of more valuable species in mixture with the western true firs. In the range of white fir (*A. concolor*), few stands have been exploited where the proportion of pines was less than 50 percent.

TABLE 2.—*Estimated virgin stand of western true firs by species*

[Revised estimates made by the Forest Service, 1931]

| Common name | Botanical name | State | Approximate virgin stand—millions of feet, board measure |
|---|---|---|---|
| White fir | *Abies concolor* | California | 28,600 |
| | | Oregon | 5,500 |
| | | Washington | [1] |
| | | Idaho | [1] |
| | | Colorado | [2] |
| | | Arizona, New Mexico | [3] 1,240 |
| | | All | 35,340 |
| Lowland white fir | *A. grandis* | California | 2,200 |
| | | Oregon | 4,500 |
| | | Washington | [4] 2,300 |
| | | Idaho, Montana | [4] 9,670 |
| All | | | 18,670 |
| Red fir | *A. magnifica* | California | 23,300 |
| | | Oregon | [5] |
| All | | | 23,300 |
| Silver fir and noble fir | *A. amabilis* and *Abies nobilis* | Oregon | [6] 10,920 |
| | | Washington | 26,800 |
| All | | | 37,720 |
| Alpine fir | *A. lasiocarpa* | Washington | [1] |
| | | Oregon | [5] |
| | | Idaho | 2,990 |
| | | Montana, Wyoming, Utah | 860 |
| | | Colorado | [4] 1,640 |
| All | | | 5,490 |
| Total | | | 120,520 |

[1] Included with lowland white fir.
[2] Included with alpine fir.
[3] Includes corkbark fir.
[4] Includes white fir (*Abies concolor*).
[5] Included with noble and silver fir.
[6] Includes alpine fir and red fir.

In parts of its wide range in California, white fir (*Abies concolor*) is associated in the forest with sugar pine, ponderosa pine, incense cedar, red fir, Douglas fir, and Jeffrey pine (fig. 4). Proportions of each species per acre and size of timber in a mixed stand of the sugar pine-white fir type are given in table 3. Occasionally in this type of stand white fir (*A. concolor*) trees measure 6 feet or more in diameter (fig. 4, *C*) and 200 feet in total height. In northeastern California and

south-central Oregon, the forest is largely pure ponderosa pine and ponderosa pine-white fir. In this area, as a whole, the virgin timber stands of the types now considered merchantable will average about 20 percent white fir (*A. concolor*), 7 percent Douglas fir and incense cedar, and 73 percent ponderosa pine and sugar pine. The largest white fir (*A. concolor*) trees in northeastern California are rarely over 40 inches in diameter or greater than eight 16-foot logs in merchantable heights. The bulk of the timber now logged from this area

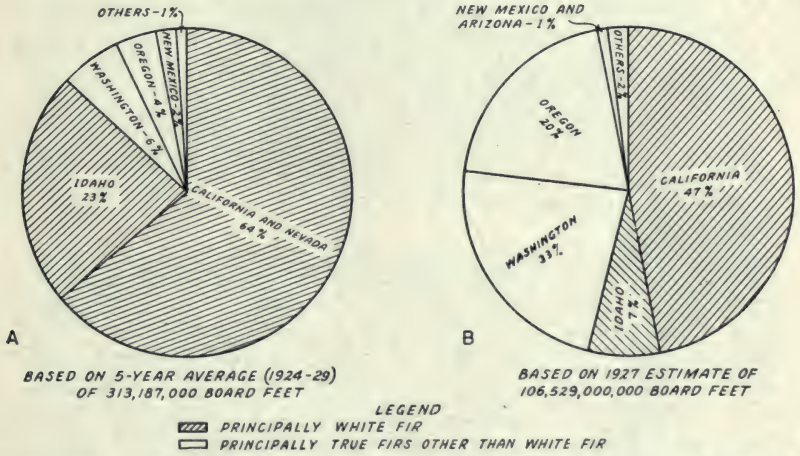


FIGURE 2.—The annual lumber cut and the saw-timber stand of western true firs: *A*, Cut of true western firs by States; *B*, stand of true western firs by States.

varies between 16 and 36 inches in diameter and averages about seven 16-foot logs to a thousand feet, net scale.

TABLE 3.—*Average number of trees of each species by size groups, volume per acre, and maximum size of trees in a stand of the sugar pine-white fir (Abies concolor) type on the western slope of the Sierra Nevada Range*

| Species | Trees per acre at a diameter breast height of— | | | Volume per acre | | Maximum size of tree in stand | |
|---|---|---|---|---|---|---|---|
| | 12 to 23 inches | 24 to 41 inches | 42 inches and over | 12 inches and over diameter breast high | Percentage of total | Diameter breast high | 16-foot logs per tree |
| | *Number* | *Number* | *Number* | *Board feet* | *Percent* | *Inches* | *Number* |
| Incense cedar | 3.75 | 3.84 | 1.23 | 6,635 | 11.2 | 64 | 8.0 |
| Sugar pine | 3.58 | 2.51 | 2.54 | 20,374 | 34.4 | 80 | 11.0 |
| Ponderosa pine | .59 | 1.45 | 1.36 | 11,690 | 19.7 | 74 | 11.5 |
| White fir (*Abies concolor*) | 13.08 | 6.33 | 1.60 | 20,585 | 34.7 | 65 | [1] 10.0 |

[1] The average white fir (*Abies concolor*) log produced 344 board feet, net log scale, by the Scribner decimal C rule or 364 board feet, gross log scale. On the net scale the logs averaged 2.9 to each 1,000 board feet; gross log scale, 2.75 to each 1,000 board feet.

Being quite tolerant of shade, the branches of white fir persist on the lower part of the trunk until maturity, resulting in a much smaller percentage of select grades than is commonly obtained from the pines. In addition many of the logs that would qualify for this grade on the basis of size and clearness contain so much decay that they are left in

the woods. In the pines, 2 and 3 grade 1 logs are fairly frequent in mature trees, but it is exceptional to find 2 clear logs in a white fir tree. In a typical stand in Tuolumne County, Calif., only 9 percent of all white fir (*Abies concolor*) logs brought to the mill could be classified as grade 1. Of the remainder, 52 percent were grade 2

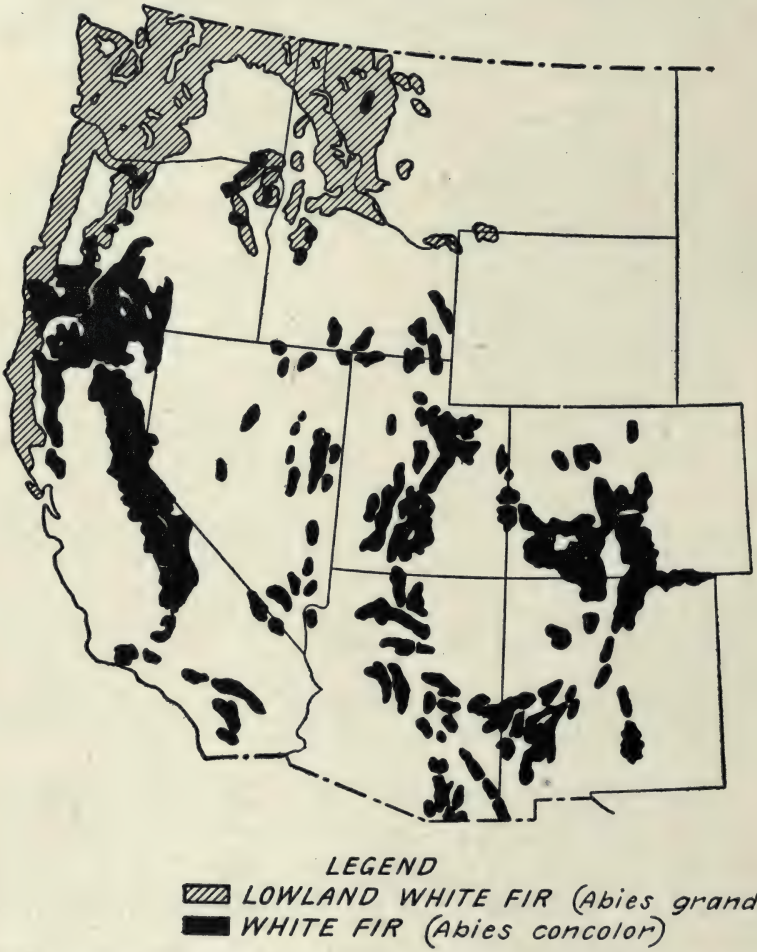


FIGURE 3.—Distribution of white fir (*Abies concolor*) and lowland white fir in the United States (*20*).

logs of the small-knotted common type and 39 percent were grade 3 of the large-knotted common type.

Lowland white fir (p. 2) is second of the western true firs in amount of lumber cut. About one twelfth of the stand and one fourth of the cut of the true firs are of this species. The botanical range includes southern British Columbia, western Montana, Idaho, Oregon, Washington, and northwestern California (*21*). The species seldom occurs in pure stands with the exception of small areas.

In the Inland Empire the lowland white fir tree on the best sites attains a diameter of 3 feet and a maximum height of about 140 feet.

FIGURE 4.—*A*, Mixed sugar pine, ponderosa pine, and white fir virgin forest on the Sierra Nevada Range. The darker, rough-barked tree near the man in the foreground is a white fir (*Abies concolor*). The lighter-colored tree with smooth bark is ponderosa pine. *B*, Mature and overmature white fir (*A. concolor*) left on logged area. *C*, A white fir (*A. concolor*) tree 68 inches in diameter.

The average mature trees to be found on any site are usually not over 18 inches in diameter and 80 feet in height (*15*). In California it is associated chiefly with redwood and Douglas fir. It forms only about 3 percent of the stand. Here on the better sites, it grows somewhat taller than white fir (*Abies concolor*), but seldom attains a diameter greater than 4 feet. It is less tolerant of shade, has more clear length, and is less defective than white fir (*A. concolor*) of California

### EFFECT OF WHITE FIR ON FOREST MANAGEMENT

The lumber user, for whom this bulletin has been primarily prepared, is not particularly interested in the forest-management problems of the silviculturist and the lumberman. Furthermore, within the wide range of the western true firs (p. 2) the numerous variations in silvicultural and lumbering problems arising from the many local variations in climatic, stand, and topographic conditions and lumber-marketing considerations cannot adequately be covered in anything less than a separate bulletin. However, a brief discussion of some of the more important aspects of timberland management in the region where most of the white fir lumber is produced will give the consumer an enlightening perspective of the unsuspecting part he plays in the sphere of western forestry when he buys white fir boards or dimension from his local retail dealer.

At present, most of the private timberland operators in the West have not made any consistent attempts to operate on a sustained-yield basis. Their cutting systems are usually based exclusively on two factors, namely, comparative lumber values by species, and defect, that is, the cull material in the trees. The species showing the highest average values are cut heavily, usually to very small tree-diameter limits. Only badly defective trees are left standing. Species of low average value are cut lightly or not at all. A few operators have recently modified their cutting practices to some extent with the idea of leaving a better reserve of growing stock, but by and large, the current profit margin derived from deducting average woods-run costs from average mill-run species value determines the cutting and utilization rules to be followed by the woods crews.

When the average selling value of white fir lumber is below the average production cost, as it has been in the past, cutting principles based on lumber values and defect naturally lead to forest deterioration in stands containing a large proportion of white fir. With trees of the more valuable species above 12 to 18 inches in diameter practically all removed, the second cut must necessarily be confined to the less valuable white fir. If the white fir were inherently resistant to decay and tree-killing insects and were preponderantly sound and thrifty in the mature classes, the result would not be so serious, but unfortunately the situation is not so favorable, directly the reverse, in fact, in the pine-white fir (*Abies concolor*) types of the Sierra Nevada.

All things considered, the evidence is convincing that the older white fir trees not removed with the first cut from the virgin forest will be practically a total loss before the second cutting takes place. But this is by no means the really serious result of such practice. Decadent and diseased trees occupy root space and use soil moisture just as truly as sound trees, regardless of the fact that they are contribut-

ing nothing to the net increment of merchantable wood. Thus they continue to retard the growth of surrounding young trees and detract further from the potential yield of the site. Badly diseased trees are also an added menace as prolific centers of infection.

Another undesirable consequence following the removal of only the pines in a mixed pine-white fir stand is the effect on the composition of future yields. White fir is usually a more prolific seeder than its associated species, the seedlings are more tolerant of shade, and it is persistent. From these factors it follows that a preponderance of white fir left on a cut-over area now will most likely result in a preponderance of white fir in succeeding generations.

White fir lumber undoubtedly will bring greater returns in the future than it brings at present, but it is hardly conceivable that it will ever be as valuable to the commonwealth as pine lumber, considered from the standpoint of uses as we are able to visualize them at present. If the greatest value is to be realized from future forest crops, therefore, the plan of management should incorporate whatever measures appear to offer the greatest likelihood of increasing, or at least of holding even the present proportion of more valuable species in the virgin stand.

The question now arises—Why has the selling price of white fir lumber, in normal times, been below the cost of production? This is a fair question because white fir lumber is intrinsically worth enough more than the price usually received for it to wipe out the operating deficit and thus allow the species at least to pay its way.

A complex of factors leading to over production of competing species and consequent demoralization of selling prices, combined with considerable prejudice traceable to unsound manufacturing and merchandising practices have made the price of white fir lumber what it is, rather than any inherent inferiority of the wood itself. White fir is now giving and has given satisfactory service wherever it has been properly manufactured, thoroughly seasoned, and intelligently used. Trouble has followed when it has been nailed in place in a green or half-dried condition, when it has been used in situations favorable for the development of wood-rotting fungi, when the wrong grades, types, and sizes of material have been substituted for the classes of stock that should have been used and when careless workmanship has resulted in the failures inevitably following a disregard of sound fabricating and construction principles.

Just as white fir occupies an important place in the general scheme of forest management wherever it occurs in appreciable quantities, so likewise should it occupy a position of importance in fulfilling many requirements of wood users. It is hoped this bulletin will help prevent in the future many of the abuses to which white fir has been subjected by describing its qualifications for particular purposes, and by explaining its peculiarities and limitations so that the consumer may know when and how it should not be used as well as when and how it should be used.

From the standpoint of sound forest management in the true fir types, it is highly important that the evils lying at the root of the existing prejudice against white fir lumber in many quarters be speedily corrected.

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## MERCHANDISING PRACTICES

### DISTRIBUTION OF LUMBER CUT

The Mississippi Valley States are the largest consumers of white fir lumber (p. 2) and take about one third of the annual cut. California consumes about one fourth of the total annual cut and about seven eighths of the cut consumed in California is home grown. The Inland Empire produced about one fourth of the total annual cut but uses less than any consuming region except the Pacific Northwest. Over one half of the white fir is shipped to distant markets (table 4).

TABLE 4.—*Distribution of the lumber cut of the western true firs* [1] *by regions*

| Place of use | Shipped from— | | | | Total | Consumption of the total production for the United States |
|---|---|---|---|---|---|---|
| | California | Inland Empire | Washington and Oregon | Rocky Mountain States | | |
| | *M board feet* | *M board feet* | *M board feet* | *M board feet* | *M board feet* | *Percent* |
| California | 69,374 | 735 | 11,605 | ---------- | 81,714 | 27.9 |
| Other States west of Rocky Mountains | 3,469 | 735 | 5,802 | ---------- | 10,006 | 3.4 |
| Rocky Mountain States | 5,203 | 736 | 3,868 | 7,370 | 17,177 | 5.6 |
| Prairie States | 13,875 | 7,353 | 5,802 | ---------- | 27,030 | 9.2 |
| Mississippi Valley States | 65,906 | 40,443 | 3,868 | ---------- | 110,217 | 37.6 |
| Atlantic coast | 15,609 | 23,531 | 7,737 | ---------- | 46,877 | 16.0 |
| Total | ---------- | ---------- | ---------- | ---------- | 293,021 | 100.0 |

[1] White fir, lowland white fir, silver fir, California red fir, and alpine fir, collectively reported by the Bureau of the Census under the name "white fir."

### PERCENTAGE OF THE CUT GOING INTO VARIOUS LUMBER ITEMS

White fir has gained its greatest popularity as construction material for small buildings, particularly as framing. For this reason, over one half of the total white fir production in California is now made into small dimension, chiefly of the 2- by 4-inch and 2- by 6-inch sizes.

Most of the select grades in white fir are usually square-edged stock although various patterns, such as ceiling, siding, and baseboard are also made in the select grades. Heavy construction timbers are manufactured frequently to fill special orders. There has been little attempt made so far to supply the general market for large sizes as a regular mill practice. Ties are produced regularly for use in logging railroads.

Table 5 shows the approximate distribution in the various lumber items of white fir marketed from California in 1931. Ties, timbers, and other material used in the manufacturers' own operations are not included.

TABLE 5.—*Percentage of white fir from California going into various classes of sawmill products* [1]

| Kind | Item and grade | Total sales |
|---|---|---|
| | | *Percent* |
| Select | Square edged and patterns, such as baseboards, siding, ceiling, and flooring of D and better grade | 3.0 |
| Dimension [2] | No. 2 and better 1 9/16 and 1 5/8 inches | 43.0 |
| | No. 2 and better 1¾ and 1⅞ inches | 7.5 |
| | No. 2 and better miscellaneous | 4.0 |
| | No. 3 dimension all thicknesses and all widths | 4.5 |
| | Total | 59.0 |
| Common | No. 3 and better common [3] | 15.5 |
| | No. 4 common | 5.0 |
| | No. 5 common | 1.0 |
| | Box lumber and box shook | 12.5 |
| | Total | 34.0 |
| Timbers | End dimensions of all sizes. Mostly less than 26 feet in length | 4.0 |
| Total | | 100.0 |

[1] Ties, timbers, and lumber used by operators are not included.
[2] Largest single item in small dimension is the nominal 2- by 4-inch size.
[3] Includes shiplap, tongue and groove, flooring, and roofing.

### SIZES IN WHICH COMMONLY MARKETED

Most of the nominal 2-inch white fir dimension shipped to the Eastern States is surfaced to 1 9/16 inches in thickness. American lumber

FIGURE 5.—A medium-sized mill operating in mixed pine and white fir (*Abies concolor*) type in central California.

standards thickness of 1⅝ inches may be obtained at a somewhat higher price but the bulk of all shipments is of the substandard size. This practice originally became established in the manufacture of pine dimension for box lumber. For surfaced 1⅝-inch dry dimension, green planks must be cut 1¾ inches thick, which means greater waste if later made into box shooks or sold as 6/4 box lumber. At the time of sawing (fig. 5) it is difficult to foretell whether a box demand or a

dimension demand will prevail later in the season, therefore the mill man cuts this stock so that it may serve a dual purpose.

An opposite departure from American lumber standards is the extra-standard white fir dimension marketed in the San Joaquin Valley of California by six nearby mills. This is surfaced to 1¾ inches and 1⅞ inches in thickness. This oversized stock, known locally as "Valley dimension", is produced specifically to compete with naturally stronger woods.

### MOISTURE CONTENT OF LUMBER AS MARKETED

The marketing of white fir in a half-dried condition is responsible more than any other thing for the current prejudice against white fir. The lumber manufacturers can remove a large part of this prejudice through proper seasoning. If they sell only good and dry white fir lumber, there is no apparent reason why a larger demand will not be forthcoming.

It has been common practice at some mills to machine and ship white fir for local use at a moisture content of more than 25 percent of the weight of the dry wood. Much of such material is not green in the sense that all of the moisture is present that was in the log when the tree was cut, which may have been from 100 to 200 percent, but it is practically equivalent to green lumber from the shrinkage standpoint (p. 12), and will be unsatisfactory if built into construction without further seasoning. Much partially seasoned white fir lumber, that is, lumber having an average moisture content of about 18 percent, has also been marketed. As a rule, lumber for eastern shipment has been more thoroughly seasoned than lumber sold locally because railroad freight charges on lumber are based on weight and therefore the longer the haul the more profitable it is to season the lumber thoroughly before shipment. If the lumber is shipped directly after removal from the green chain, the entire cost of extra handling and seasoning is saved, which means an appreciable reduction in total operating expense, but since unseasoned white fir lumber, or any unseasoned lumber for that matter, is unsuited for most of the uses to which the species is best adapted, such practice results in dissatisfaction on the part of the consumer and ultimately loss to the manufacturer. On the other hand, well-seasoned white fir is obtainable from reliable mills and reliable lumber dealers when well-seasoned lumber is specified.

## HOW TO DISTINGUISH WHITE FIR FROM OTHER WOODS

The exceptionally flat, white color of the spring wood makes it easy to distinguish white fir lumber (p. 2) from that of all but a few woods. Douglas fir, the pines, cedars, cypress, and redwood are all readily distinguished from white fir by color differences. The other true firs, hemlocks, and spruces, however, are light-colored woods which are not so easily distinguished from white fir. As a matter of fact, there is no known method of positively distinguishing the wood of white fir from that of the other true firs even with the aid of a microscope. The wood of white fir can be positively distinguished from the spruces by the resin ducts in the latter. Resin ducts are normally absent in white fir. The hemlocks are distinguished from white fir by their darker color. Individual isolated specimens, however, are

difficult to identify on the basis of color alone, and positive identification can only be made by structural differences visible under the microscope.[7] Where white fir and western hemlock lumber are mixed, as they often are, it is comparatively easy to distinguish white fir by the flat, white color of spring wood which contrasts with the darker color and silky sheen of the western hemlock. In addition the summer wood imparts a bluish-purple tinge to white fir and occasional trees yield lumber of a decided grayish hue. Although such material is quite unlike the general run of white fir in appearance it is, so far as is known, in no way inferior for general use.

## DESCRIPTIVE PROPERTIES OF WHITE FIR

### STRUCTURE, COLOR, AND ODOR OF WOOD

The annual rings of white fir (p. 2) are distinct, consisting of wide bands of spring wood and narrow bands of summer wood (pl. 1). The spring wood merges gradually with the summer wood. The result is a distinct though not pronounced figure that is similar to the figure of the spruces and the hemlocks. The figure is enhanced with natural finishes. Its attractiveness as compared with other species is a matter of personal preference. The figure is not so pronounced as that of Douglas fir but is more pronounced than that of the white pines.

White fir is a straight-grained, fine-textured wood. While it is described as straight grained, it, like many other species, contains some cross-grained material. The cross grain may have developed in the trees or in manufacturing. The amount of cross grain in white fir will probably not differ greatly from that in the principal softwoods.

The wood cells of white fir are fairly uniform in size. The summer-wood cells are thicker walled than the spring wood but summer-wood cells are comparatively few in number. The wood is therefore described as fine textured.

The heartwood and sapwood contain less color than any other of our commercial softwoods, and are therefore not distinguishable. What color exists in the lumber of both white fir (*Abies concolor*) and lowland white fir is due to a slight reddish-brown tinge in the summer wood (*9*), the spring wood of both species being flat white. There is a decided preference for light-colored or white wood in a number of uses, especially containers. This preference makes the whiteness of white fir an asset.

The lumber of white fir has a slightly disagreeable odor when green. When seasoned the wood is without distinctive odor. The odor of green wood failed to return when the wood was soaked in trials made at the Forest Products Laboratory. These trials are substantiated by tests made by the University of California (*25*) and by the fact that white-fir boxes have been used with entire satisfaction for shipping butter.

### HEARTWOOD CONTENT

The decay resistance of both the heartwood and sapwood of white fir is low; consequently the percentage of heartwood in white fir has no particular utility value.

[7] Where the necessity for such positive identification exists samples may be submitted for identification to the Forest Products Laboratory.

### ANNUAL GROWTH RINGS

White fir grows relatively fast. The annual growth rings in the lumber are therefore wider than those in most of the commercial softwoods. The rings average about 12 to the inch. The select grades average about 17 rings to the inch and common grades about 11. The width of the annual growth ring materially affects the figure of the wood but otherwise has no great practical signifinance in white fir lumber because of the fairly uniform texture within each annual ring.

### WEIGHT OF THE WOOD

White fir is one of the lightweight softwoods. In a thoroughly air-dry condition of 12-percent moisture content white fir (*Abies concolor*) weighs 26 pounds and lowland white fir, 28 pounds per cubic foot. One thousand board feet of nominal 1-inch white fir (*A. concolor*) at 12-percent moisture content surfaced to twenty-five thirty-seconds inch will weigh about 1,550 pounds in 4-inch widths or 1,600 pounds in 10-inch widths; lowland white fir in corresponding widths will weigh about 100 pounds more per thousand board feet than white fir (*A. concolor*). The actual weight of white fir lumber as shipped will vary from the foregoing weights from about 4 percent lower to 10 percent higher, depending upon the degree of seasoning. Other items of white fir will vary in weight because of degree of seasoning and because the relation of actual to nominal dimension is different. Items of pattern stock will weigh less than square-edged stock because of the material that has been removed. A comparison of the weight of the wood of white fir (*A. concolor*) and lowland white fir with a number of the important commercial softwoods is made in figure 6. The comparison is made for air-dry wood of 12 percent moisture content.

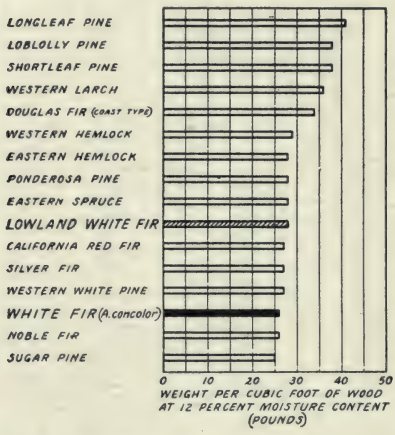



FIGURE 6.—The weight of air-dry white fir (*Abies concolor*) compared with the weight of other species.

There is little difference between the weight of white fir lumber and that of the other western true firs (p. 2). About the maximum difference to be expected in a thousand board feet of 1-inch dressed lumber at 12-percent moisture content of any of these species is 100 pounds. Douglas fir (coast type) lumber when thoroughly air-dried will weigh from 400 to 500 pounds more per 1,000 board feet than white-fir lumber. Sugar pine, on the other hand, will weigh from 50 to 200 pounds less.

The light weight of white fir is one of the properties largely accountable for the general use of the wood. It reduces cost of transporting the lumber to markets, reduces handling costs, and is a desired property in boxes and other containers.

### SHRINKAGE

White fir shrinks less than most of the other important softwoods. The average shrinkage from a green to an oven-dry condition is about

the same as that of ponderosa pine and eastern hemlock, lowland white fir having a larger and white fir (*Abies concolor*) having a slightly smaller shrinkage than these two species. The other western true firs, with the exception of alpine and corkbark fir, have a higher shrinkage than white fir as do the other species that are sold in mixture with white fir.

A comparison of the shrinkage of white fir (*A. concolor*) with the shrinkage of other softwoods is shown in figure 7. The comparison is based on the total shrinkage from a green to an oven-dry condition.

Small change in dimension from swelling and shrinking is a property desired in practically all uses, even in such uses as subfloors,

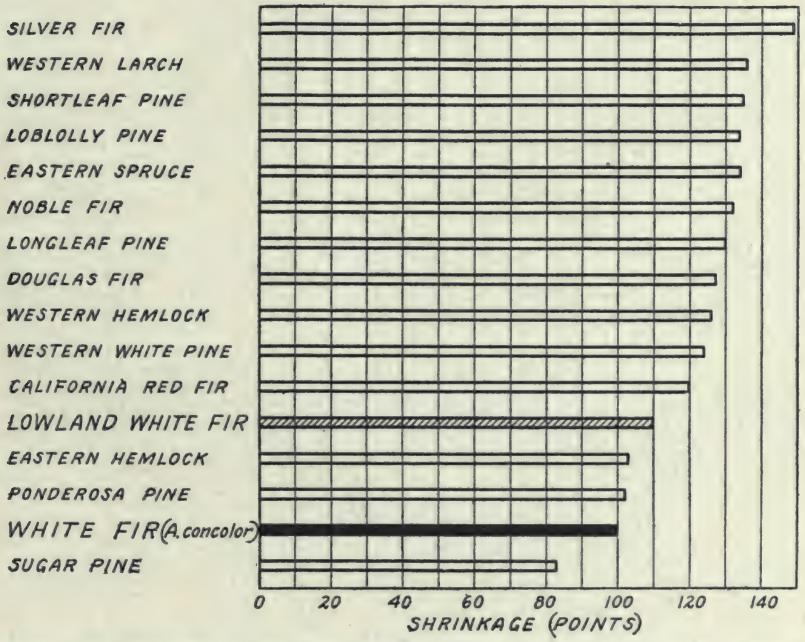



FIGURE 7.—The shrinkage of white fir (*Abies concolor*) compared with other species. White fir (*A. concolor*) is taken as 100 points.

sheathing, or concrete forms. In the more exacting uses, such as window sash, doors, and interior trim, small shrinkage is of prime importance. The comparison of the shrinkage of white fir (*Abies concolor*) and lowland white fir with that of other woods indicates that their shrinkage is small enough to meet the requirements of both rough and of many exacting uses.

The average shrinkage to be expected in white fir lumber between any given moisture conditions can be obtained from figure 8. For example, to determine the average change in dimension of 1 by 8 inch flat-grained white fir subflooring between 6 and 12 percent moisture, a horizontal line through 6-percent moisture meets the curve representing flat grain at 5.4 percent; a similar line through 12 percent meets the same curve at 3.7 percent. The difference between the two values is 1.7 percent. The difference multiplied by 7⅝, the actual width of nominal 8-inch boards, gives the amount each board

will shrink, which is about one eighth of an inch. The curves of figure 8 are based on measurements made on short sections of boards selected from the commercial run of white fir lumber at a mill in the Inland Empire. A convenient rule-of-thumb for determining dimension change in percentage is to multiply the moisture change in percentage by one sixth for edge-grained and by one fourth for flat-grained lumber for the change in dimension of an 8-inch flat-grained board. This corresponding to a 6-percent change in moisture content would be $6 \times \frac{1}{4}$ or 1.5 percent of 8 inches, or about one eighth of

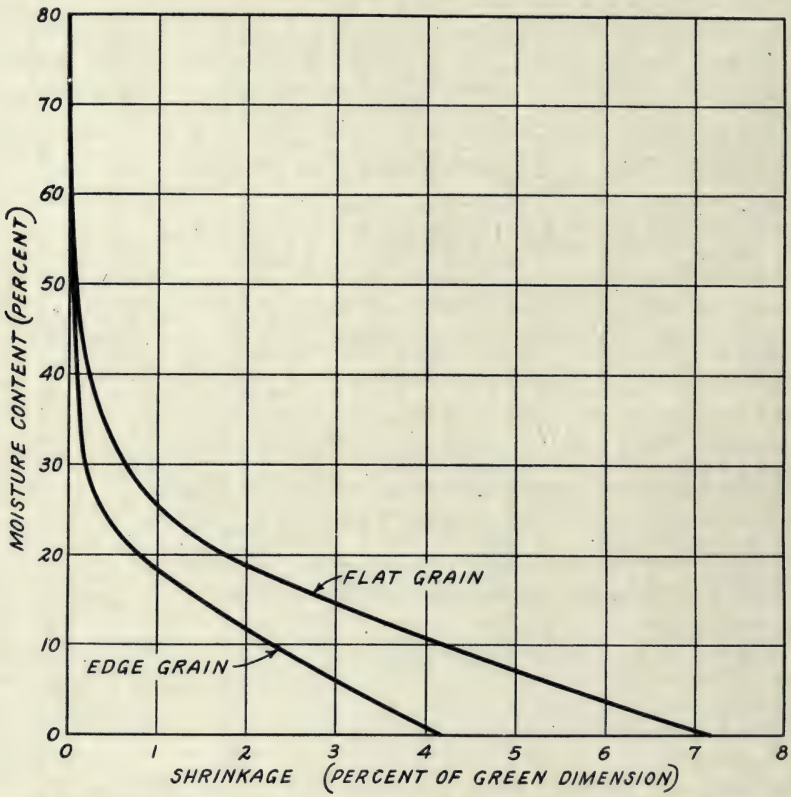
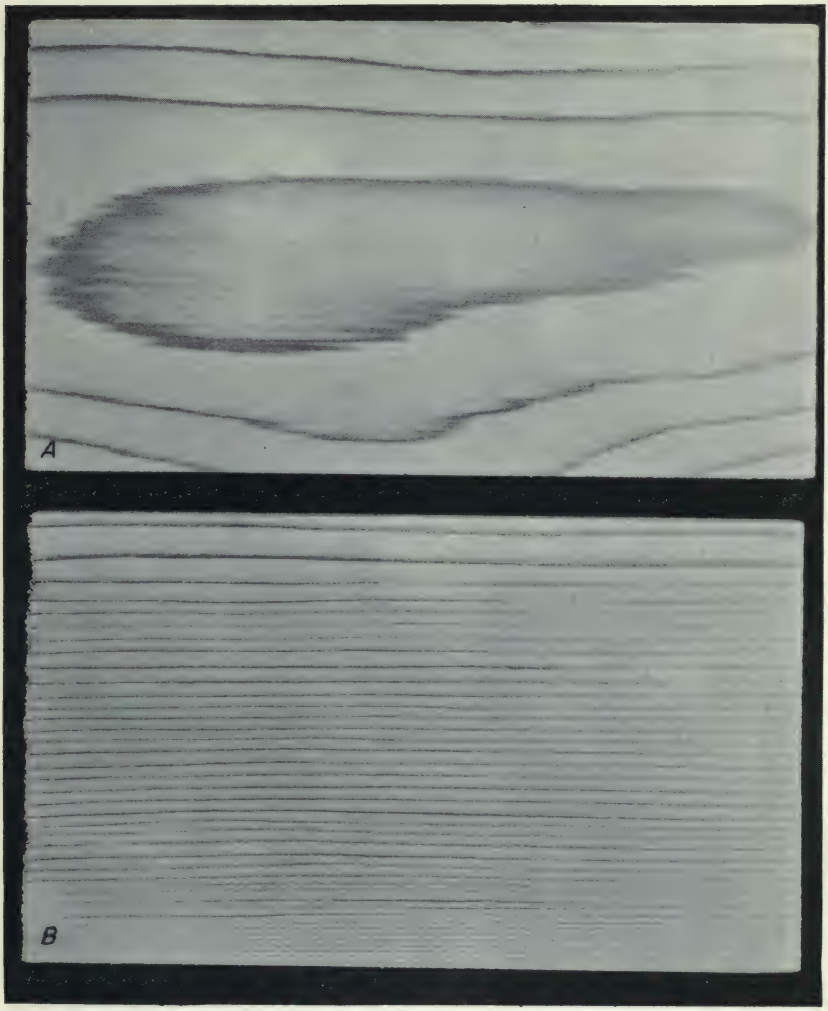



FIGURE 8.—Shrinkage of flat- and edge-grained white fir. Based on tests of 1-inch boards selected from commercial run of lumber. The chart may be used to determine the change in dimension that will take place with changes in moisture content of wood.

an inch. In an 8-inch, edge-grained board the change would be $6 \times \frac{1}{6}$ or 1 percent, or about one twelfth of an inch.

When the marketing practices are considered, it is not difficult to understand why the moderately small shrinkage of the white fir has not created a more favorable impression. The marketing of wet or insufficiently dried wood has more than offset any advantages the species have as a result of their inherently small shrinkage. White fir lumber marketed at more than 25-percent moisture content, if used in the interior of buildings, will probably dry to 6 percent in moisture content when the buildings are heated. The shrinkage in an 8-inch flat-grained board under such conditions is shown by figure




TYPICAL FLAT-GRAINED AND EDGE-GRAINED WHITE FIR.

A, Flat grain. B, Edge grain.

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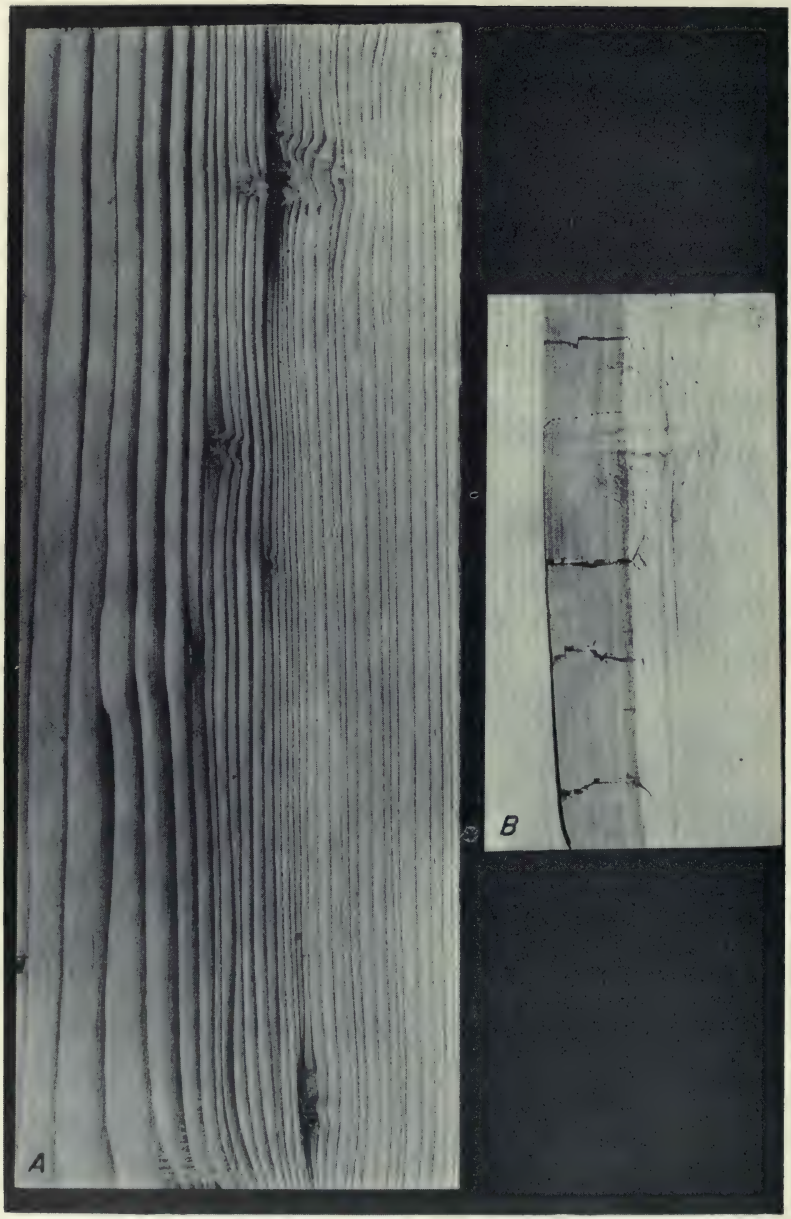


Dark streak in white fir. B, Pronounced compression wood is shown by the darker colored band. Note the cross breaks resulting from the excessive longitudinal shrinkage of this abnormal wood.

8 to be about one third of an inch, which is too large a shrinkage for most uses. So long as any large proportion of white fir lumber is marketed before it is adequately seasoned the wood will not acquire the reputation for small or moderately small shrinkage to which it is entitled.

## CHARACTERISTIC DEFECTS

The characteristic defects of a species not only affect the appearance but also determine the suitability of the lumber for specific uses. A detailed tally was made of all defects in 20,000 board feet of 1- by 8-inch white fir (p. 2) boards. One half of the material was studied at 2 mills in the Inland Empire and one half at 1 mill in California.

There was a marked difference in the character of the defects between the white fir lumber from the Inland Empire and that from California. Part of this difference was because the grades are not identical (p. 41) and part because of species differences. The defects found in the lumber of the two sections are therefore presented separately. Table 6 tabulates the occurrence of the principal defects found in the various grades in the two regions.

TABLE 6.—*Occurrence of defects in white fir lumber as shipped from California and the Inland Empire*

| Defect | Occurrence of defects expressed as percentage of all boards studied | | | | | |
|---|---|---|---|---|---|---|
| | California [1] | | | Inland Empire [2] | | |
| | C and Better | No. 2 and Better | No. 3 Common | D and Better | No. 3 and Better | No. 4 Common |
| Knots | 41 | 92 | 98 | 92 | 100 | 100 |
| Checks | 13 | 16 | 28 | 26 | 38 | 59 |
| Wormholes | 8 | 7 | 9 | 1 | 2 | 6 |
| Stain | 5 | 4 | 3 | 5 | 5 | 14 |
| Torn grain | 6 | [3] | [3] | 12 | [3] | [3] |
| Dark streaks | 3 | [3] | [3] | 52 | [3] | [3] |
| Splits | 1 | 4 | 7 | 4 | 25 | 45 |
| Shake | | 3 | 3 | 2 | 4 | 4 |
| Wane | | 2 | 2 | 1 | 4 | 7 |
| Decay | | 1 | 8 | | 6 | 17 |
| Pith | | 1 | | | 5 | 8 |
| Holes | | | | 10 | | |
| Skips | | | | 4 | | |
| Burn | | [3] | [3] | 2 | [3] | [3] |

[1] Based on 10,400 board feet principally of white fir (*Abies concolor*).
[2] Based on 9,400 board feet principally of lowland white fir.
[3] This defect did not affect the grade and therefore was not recorded.

Defects are of three general types: natural, seasoning, and manufacturing. Natural defects develop in the growing tree. Seasoning and manufacturing defects develop during logging, milling, or storage. The natural defects are distinctly characteristic of species. Seasoning and manufacturing defects, on the other hand, are primarily indicative of methods used in manufacture but do show certain species tendencies. Thus the amount of checking found in the lumber is dependent largely upon the seasoning methods used but a species with a large difference between radial and tangential shrinkage will check more than one with more uniform shrinkage.

## NATURAL DEFECTS

### KNOTS

The knots of white fir as compared with those of other softwoods are in general intermediate in size and number. In the mill run of white fir, the knots averaged slightly over one half inch in diameter and there were about 1,200 to a thousand board feet. The knots averaged about the same size as those in western hemlock, were smaller than those in eastern hemlock, and larger than those in Douglas fir (coast type). A large proportion of the knots in white fir were black. They were exceptionally free from decay, but a higher percentage were loose, broken, or checked than in any of the other species studied.

The difference in the size and number of the knots in white fir from California and the Inland Empire is shown in detail in table 7. White fir lumber in the Inland Empire contained more than twice as many knots as the white fir lumber of California. The knots in the white fir of the Inland Empire were, however, much smaller.

TABLE 7.—*Size and number of knots in white fir lumber* [1]

| Place of growth | Grade | Knots per thousand feet board measure | Average diameter | Percentage of all boards containing the defect |
|---|---|---|---|---|
| | | *Number* | *Inch* | *Percent* |
| California | C and Better | 89 | 0.41 | 41 |
| | No. 2 and Better | 849 | .71 | 92 |
| | No. 3 Common | 1,059 | .88 | 98 |
| Inland Empire | D and Better | 636 | .30 | 92 |
| | No. 3 and Better | 2,163 | .46 | 100 |
| | No. 4 Common | 2,300 | .48 | 100 |

[1] Based on 20,000 board feet studied by the Forest Products Laboratory.

### PITCH DEFECTS

White fir is nonresinous [8] and normally contains no pitch pockets, pitch streaks, or pitch in any form. The absence of these defects is a decided advantage where lumber is to be painted or where odor, taste, or exudations are objectionable.

### SHAKE

About 1 board in every 33 of the white fir studied contained shake. Of the 14 commercial softwoods included in the study, 4 showed less and 9 showed more shake than white fir. Ponderosa pine had about one third as much shake and shortleaf pine about twice as much as white fir. Though the amount of shake in white fir was small, when it did occur it was of a severe type. There was no great difference between the shake found in white fir lumber from the Inland Empire and that from California.

### DARK STREAKS

Dark streaks are peculiar to the western true firs (p. 2) and western hemlock. They consist of dark brown or black scars result-

[8] Occasionally as a result of injury to tree resin ducts and pitch pockets are formed. They are rare and insofar as the use of the wood is concerned, are of no practical importance.

ing from the attack of the fir bark beetle. In edge-grained boards the scars appear as thin streaks or seams ranging from a few inches to several feet in length. In flat-grained boards they appear as small, black bark pockets (pl. 2, *A*). The streaks are so narrow in edge-grained boards that they are not considered defects in any lumber grades. In the common lumber neither the streaks nor the bark pockets are considered defects. From one third to one half of the white fir lumber studied in the Inland Empire, depending on grade, had dark streaks. In white fir from California dark streaks occurred in only 3 to 10 percent of the lumber. The frequency of the occurrence of dark streaks is therefore a rough indication of the region from which the material was cut.

#### DECAY

In the study of the defects in 1-inch boards decay was found more frequently in white fir than in most woods. About 1 piece in 11 contained decay as compared with about 1 piece in 10 of western white pine and 1 piece in 24 of Douglas fir (coast type). No decay, however, was found in the select grades. Practically all of the decay found in the better common grades of white fir from both California and the Inland Empire was incipient. Advanced decay was present in from 4 to 5 percent of the lumber of the third grade in each region. Pieces having either advanced or incipient decay should not be used where strength is an important requirement.

#### WORMHOLES

The wormholes in white fir were principally pinholes. In the white fir from the Inland Empire 1 to 6 percent of the pieces studied had wormholes and in that from California 7 to 9 percent. Except in certain uses of C and better grade, the wormholes are of little importance. The effect of wormholes upon strength is negligible except in very small pieces.

#### PITH

Pith is a defect of minor importance and occurs only occasionally in lumber of any species. The select grades of white fir showed no pith and it was present in only from 1 to 8 percent of the lumber of the common grades.

#### CROSS GRAIN

The grading rules do not class cross grain as a defect in the yard lumber of any softwood species. No mention is made of it in the grading rules for white fir. Cross grain, however, is a serious defect because of its injurious effect upon the strength. It is also responsible for much of the warping of the twisting type.

#### COMPRESSION WOOD

Compression wood (*18*) is abnormal wood (pl. 2, *B*). It is generally somewhat darker than the normal wood and is characterized by a lack of strong contrast between summer wood and spring wood. It shrinks longitudinally much more than normal wood and therefore is objectionable in lumber because the longitudinal shrinkage causes lumber to warp and in extreme cases to rupture. In service, compression wood is often responsible for open joints.

A study of the occurrence of compression wood in white fir showed that about one fourth of the lumber contained varying amounts of compression wood. About three fourths of this compression wood was of such a type that it would not seriously injure the serviceability of the lumber. Although the lumber grader takes no account of compression wood, the twisting and cross breaks resulting from it cause the worst of it to be eliminated at the mill or the lumber containing it to be dropped into the lowest grades that go into less exacting uses.

Observations were also made on the compression wood in ponderosa pine, sugar pine, and western white pine. In two of these species compression wood occurred with about the same frequency as it did in white fir and in all three species the type of compression wood that causes cross breaks was more prevalent than it was in white fir. The problem of compression wood is, therefore, not peculiar to white fir, but is common to most of the commercial softwoods.

### SEASONING DEFECTS

White fir has acquired a worse reputation for seasoning defects than it deserves. This reputation is based on behavior of partially seasoned lumber in service. The partially seasoned lumber exposed to the sun and wind in service dries too rapidly, and, only one side being exposed, dries unevenly. The checking and splitting that result are consequently much worse than would occur in the seasoning pile.

About one third of the thoroughly seasoned white fir lumber studied was checked, about one fifth contained splits, and about one sixteenth was stained. All but 3 of the 14 softwood species studied showed less checking and splitting than white fir. About one half of the species studied showed more staining.

The more general use of dry kilns and the improvement of seasoning practices and drying schedules will reduce the number and seriousness of the seasoning defects, especially in white fir.

### CHECKS

White fir has a tendency to check. The tendency is partly because of the large difference between the radial (edge grain) and the tangential (flat grain) shrinkage. In both white fir (*Abies concolor*) and lowland white fir the tangential shrinkage is more than twice the radial shrinkage. Practically all the commercially important softwood species were studied and few had as many checks as white fir and in addition the checks in white fir were somewhat worse. The percentage of the pieces of white fir having checks and the types of checks are shown in table 8. The white fir from the Inland Empire had considerably more checks than that from California. The difference, however, was not important, for it was due principally to the greater number of end checks in the Inland Empire material. The lumber from the two regions did not differ greatly in the types of checks that seriously affect the serviceability.

TABLE 8.—*Percentage of pieces of white fir having checks* [1]

| Place of growth | Grade | Small surface checks | Medium surface checks | Large surface checks | End checks | Through checks | All types |
|---|---|---|---|---|---|---|---|
| California | C and better | 9 | | | 4 | | 13 |
| | No. 2 and better | 8 | 1 | | 5 | 3 | 16 |
| | No. 3 Common | 4 | 5 | | 8 | 16 | 28 |
| Inland Empire | D and better | 8 | 3 | | 16 | | 26 |
| | No. 3 and better | 10 | 11 | 1 | 18 | 3 | 38 |
| | No. 4 Common | 10 | 15 | | 35 | 13 | 59 |

[1] Based on 20,000 board feet studied by the Forest Products Laboratory.

### SPLITS

White fir had more splits than most woods studied. The white fir from California had less and shorter splits than that from the Inland Empire. The percentage of splits found in the different grades of the white fir from the two regions is shown in table 9.

TABLE 9.—*Percentage of pieces having split in white fir* [1]

| Place of growth | Grade | Short split | Medium split | Long split | All types |
|---|---|---|---|---|---|
| California | C and better | 1 | | | 1 |
| | No. 2 and better | 2 | 3 | | 5 |
| | No. 3 Common | 2 | 4 | 1 | 7 |
| Inland Empire | D and better | 2 | 2 | | 4 |
| | No. 3 and better | 12 | 11 | 2 | 25 |
| | No. 4 Common | 17 | 18 | 10 | 45 |

[1] Based on 20,000 board feet studied by the Forest Products Laboratory.

### STAIN

The sapwood of white fir lumber, although it can be readily stained under laboratory conditions, remains exceptionally free from stain discolorations in the seasoning pile and in use even where moisture conditions are highly favorable for the growth of staining fungi. The sapwood of green ponderosa pine and sugar pine lumber when piled for seasoning on pine stickers ordinarily discolors where stickers and boards are in contact, but when piled on white fir stickers, contact stains are greatly reduced. In parts of California, where staining conditions are quite severe during the fall and winter, white fir logs are frequently accumulated in storage by the operators during the summer in order that the other species may be sawed and piled before staining weather sets in. White fir lumber may be piled regardless of weather conditions with practically no danger of stain depreciation.

In studies of lumber defects less stain was found in white fir than in woods associated with it in the forest and at the mill. The amount of medium and heavy stain in white fir was negligible. Stain was found in 5 percent of the pieces in the select grades from both the Inland Empire and California; however, this stain was so light that it would not be objectionable in lumber to be painted. The stain found in the common grades of white fir would practically never be objectionable in uses to which this class of lumber is put.

TABLE 10.—*Average mechanical and physical properties of the clear wood of white fir compared with other species* [1]

| Species of wood | Specific gravity based on weight when oven dry and volume when green | Weight per cubic foot | | Composite or index values [2] (white fir taken as 100 points) for— | | | | | | | | Strength at 12-percent moisture content | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Green | At 12-per cent moisture content | Shrinkage | Bending strength | Compressive strength (endwise) | Stiffness | Hardness | Shock resistance | Splitting resistance | Nail holding power | Modulus of rupture | Compression parallel to grain |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) | (12) | (13) | (14) |
| | | *Pounds* | *Pounds* | *Points* | *Points* | *Points* | *Points* | *Points* | *Points* | *Points* | *Points* | *Pounds per square inch* | *Pounds per square inch* |
| Cedar, western red (*Thuja plicata*) | 0.31 | 27 | 23 | 80 | 83 | 101 | 85 | 90 | 87 | 75 | 104 | 7,800 | 5,120 |
| Cypress, southern (*Taxodium distichum*) | .42 | 50 | 32 | 109 | 110 | 126 | 107 | 124 | 127 | 105 | 146 | 10,600 | 6,390 |
| Douglas fir (*Pseudotsuga taxifolia*) (coast type) | .45 | 38 | 34 | 127 | 125 | 147 | 143 | 141 | 135 | 99 | 149 | 12,300 | 7,650 |
| Douglas fir (*Pseudotsuga taxifolia*) (Inland Empire type) | .41 | 37 | 31 | 118 | 111 | 123 | 125 | 138 | 120 | 125 | | 11,400 | 6,800 |
| Douglas fir (*Pseudotsuga taxifolia*) (Rocky Mountain type) | .40 | 35 | 30 | 108 | 104 | 114 | 112 | 124 | 112 | 109 | | 9,600 | 6,140 |
| Fir, alpine (*Abies lasiocarpa*) | .31 | 28 | 23 | 97 | 71 | 78 | 74 | 79 | 60 | 81 | | 6,800 | 4,100 |
| Fir, balsam (*Abies balsamea*) | .34 | 45 | 26 | 108 | 82 | 92 | 93 | 74 | 83 | 69 | | 7,800 | 4,700 |
| Fir, lowland white (*Abies grandis*) | .37 | 44 | 28 | 110 | 100 | 112 | 123 | 102 | 120 | 88 | 87 | 9,400 | 5,600 |
| Fir, noble (*Abies nobilis*) | .35 | 30 | 26 | 133 | 103 | 104 | 118 | 93 | 113 | 85 | | 10,200 | 5,660 |
| Fir, California red (*Abies magnifica*) | .37 | 48 | 27 | 120 | 108 | 101 | 105 | 124 | 118 | 118 | | 10,800 | 5,330 |
| Fir, silver (*Abies amabilis*) | .35 | 36 | 27 | 149 | 97 | 104 | 116 | 88 | 117 | 94 | 107 | 9,600 | 5,650 |
| Fir, white (*Abies concolor*) | .35 | 47 | 26 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 9,300 | 5,420 |
| Hemlock, eastern (*Tsuga canadensis*) | .38 | 50 | 28 | 103 | 100 | 108 | 95 | 121 | 112 | 81 | 120 | 8,900 | 5,490 |
| Hemlock, western (*Tsuga heterophylla*) | .38 | 41 | 29 | 126 | 103 | 115 | 113 | 119 | 122 | 100 | 143 | 10,000 | 6,200 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Larch, western (*Larix occidentalis*) | .48 | 48 | 36 | 136 | 124 | 142 | 120 | 152 | 135 | 94 | 163 | 11,800 | 7,480 |
| Pine, loblolly (*Pinus taeda*) | .50 | 54 | 38 | 134 | 129 | 142 | 131 | 148 | 155 | 114 | 159 | 13,000 | 8,200 |
| Pine, longleaf (*Pinus palustris*) | .55 | 50 | 41 | 131 | 147 | 168 | 149 | 181 | 172 | 119 | 194 | 15,500 | 9,060 |
| Pine, shortleaf (*Pinus echinata*) | .49 | 51 | 38 | 135 | 135 | 142 | 134 | 162 | 185 | 128 | 186 | 13,400 | 7,860 |
| Pine, sugar (*Pinus lambertiana*) | .35 | 51 | 25 | 83 | 89 | 93 | 88 | 90 | 92 | 107 | ---- | 8,100 | 4,770 |
| Pine, western white (*Pinus monticola*) | .36 | 35 | 27 | 124 | 96 | 103 | 108 | 83 | 108 | 95 | 132 | 9,600 | 5,720 |
| Pine, ponderosa (*Pinus ponderosa*) | .38 | 45 | 28 | 102 | 90 | 95 | 88 | 98 | 97 | 115 | 120 | 9,300 | 5,340 |
| Redwood (*Sequoia sempervirens*) | .39 | 52 | 28 | 71 | 115 | 141 | 108 | 129 | 108 | ---- | ---- | 10,100 | 6,200 |
| Spruce, eastern (average of red and white) | .37 | 34 | 28 | 134 | 97 | 103 | 102 | 93 | 112 | 92 | 115 | 9,900 | 5,720 |
| Percentage estimated probable variation of an individual piece | 8.0 | ---- | ---- | 12 | 12 | 14 | 18 | 16 | 20 | ---- | ---- | ---- | ---- |

[1] This table is for use in comparing species either in the form of clear lumber or in grades containing like defects, except structural material. Structural material which conforms to American lumber standards should be compared by means of allowable working stresses, values for which are presented in table 22.

[2] For derivation of composite values except splitting resistance and nail-holding power see Markwardt (*11*).

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### MANUFACTURING DEFECTS

Skips, holes, and wane were not exceptional in either occurrence or character in the white fir examined. They corresponded about to the average found in other softwoods. Broken knots were more frequent than in most species. Manufacturers complain of the degrade resulting from the breaking of knots in planing especially when planing wood that is thoroughly dry. All species of wood having a high percentage of black knots give trouble from knots breaking. Much can be done to decrease this breakage by regulating the speed of the feed, by careful setting of planer knives, and by keeping the knife edges sharp. Attempting to decrease knot breakage by dressing the lumber wet as is sometimes done results in poor surfaces.

Manufacturing defects in the lower grades of white fir, aside from broken knots, are relatively unimportant as compared to natural and seasoning defects. The frequency with which the important manufacturing defects occur under present manufacturing practice is shown in table 6.

## MECHANICAL OR STRENGTH PROPERTIES OF THE WOOD

Wood users generally evaluate a species in terms of other species. The best basis for the comparison of species is the strength of the clear wood. The strength of clear wood is the inherent strength of the wood fibers of the species. Such factors as moisture, defects, size, and the like, have been eliminated, controlled, or adjusted. The following comparisons of the strength properties of the white fir (*Abies concolor*) with those of other species are made on the basis of the strength of the clear wood. White fir (*A. concolor*) is represented as 100 points in order that comparisons may be made with other species by a glance at table 10 or the figures. White fir (*A. concolor*) was chosen as the base in preference to lowland white fir because more lumber is cut from the former, and because some of its strength properties are somewhat lower than those of lowland white fir. When there is no way of knowing from which of the two species the white fir lumber was cut, it is safer and more conservative to use data on the weaker species.

White fir (*Abies concolor*) and lowland white fir are treated separately in tables, graphs, and the discussion of mechanical porperties. This is possible because data are based on material selected in the woods and carefully identified as to species. No attempt has been made to combine any species except that red and white spruce are combined as eastern spruce because lumber of these species is best known by that name.

The comparisons in table 10 are of averages. A knowledge of the probable departure of individual pieces from these averages is often of value. This information is shown in the bottom line of table 10. That is, in any shipment about one half of the material will vary from an average less than the percentage shown in the bottom line of the table, or in other words, there is a 50–50 chance that an individual sample selected at random will not vary from the average more than the percentage shown.

### BENDING STRENGTH

White fir (*Abies concolor*) and lowland white fir have the same bending strength. The bending strength of these woods is the same as that of eastern hemlock. In this property they are somewhat higher than ponderosa pine or western white pine, but considerably lower than Douglas fir (coast type) or the southern yellow pines (fig. 9). Eastern spruce and eastern hemlock have for years been extensively used for framing, roofing, subfloors, crates, and other uses in which bending strength is required. White fir will meet requirements for bending strength equally well as these species.

Of the species sold in mixture with white fir, only alpine fir is weaker in bending strength. Western hemlock and California red fir have approx-

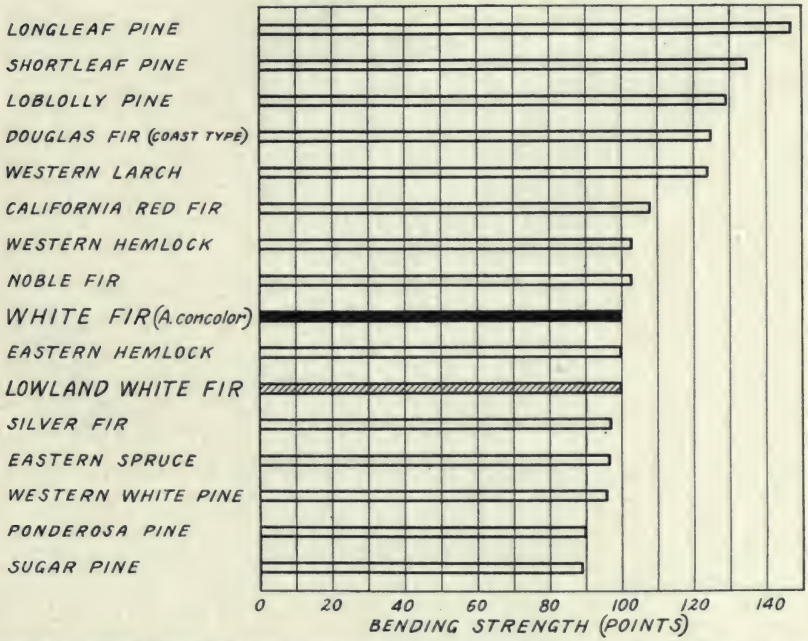



FIGURE 9.—Bending strength of white fir (*Abies concolor*) compared with that of other species of wood. The comparison shown here is for clear wood. The defects present, difference in dressed dimension, or moisture content may change the comparisons.

imately the same bending strength as white fir. The silver and noble firs likewise have about the same bending strength as white fir and can also be used interchangeably with it. Alpine fir should not be mixed with white fir lumber because the former has lower bending strength.

The bending strength of lumber is dependent more upon the defects present than upon the strength of the clear wood. The strength of joists, rafters, and structural timber is therefore largely a matter of grade. Comparison of the bending strength of structural material should be based on working stresses for fiber stress in bending shown on page 52.

The bending strength of white fir adapts it particularly to dwelling-house and other light construction. White fir can be used in structural sizes for bridges and mill-type construction, but such timbers of white fir must be larger than those of Douglas fir, western larch, and other heavier species in order to obtain the same bending strength.

### COMPRESSIVE STRENGTH (ENDWISE)

White fir is in a group of softwoods that have about the same compressive strength (endwise). The group includes eastern hemlock, eastern spruce, and noble, silver, and California red firs (fig. 10). Lowland white fir is the strongest of the group and white fir (*Abies concolor*) the weakest. The difference between the two white firs is about 12 percent. The group is considerably lower in compressive strength

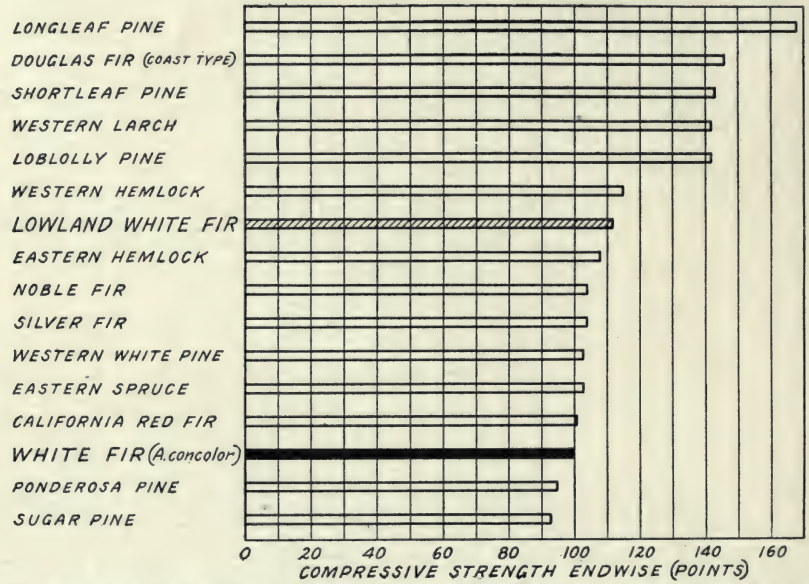



FIGURE 10.—Compressive strength of clear wood of white fir (*Abies concolor*) compared with that of other woods. The effect of defects, difference in dressed dimension, or moisture content may change the comparisons.

than the heavier woods, such as Douglas fir, southern yellow pine, and western larch, but is slightly higher than lightweight softwoods, such as western white pine, northern white pine, sugar pine, and ponderosa pine. All of the species in the group are interchangeable in uses where compressive strength (endwise) is an important requirement.

White fir posts and short columns in small houses and light construction need be no larger than those of woods with much higher compressive strength. The posts required to obtain the desired bearing area, stiffness, or stability for such uses are large enough to carry much greater loads than are ever placed upon them. Posts in small houses, therefore, do not fail from overloading. Post supports for bins and posts for similar heavy construction may be subjected to loads of sufficient size to cause failure. In such industrial uses white fir posts must be larger than posts of Doughlas fir (coast type), southern yellow pine, and other heavy or moderately heavy woods in order to have the same load-carrying capacity. The safe load-carrying capacity of structural timbers can be determined from working stresses given on page 52.

### SHOCK RESISTANCE OR TOUGHNESS

Shock resistance or toughness is the capacity to withstand suddenly applied loads, a property desirable in some degree for practically all

uses, but particularly essential for wood subjected to repeated shocks, jars, jolts, and blows. For uses such as tool handles, wheel spokes, and athletic equipment, where shock resistance is the principal requirement, only the heaviest hardwoods like hickory, ash, and elm can be used. On the other hand, where a degree of toughness is desired and it is equally or more important to have light weight, uniform texture, ease of working, or a combination of these or other properties as in ladder rails, boxes, and joists, the softwoods are preferred. White fir can meet requirements that permit the use of the lighter-weight softwoods but cannot be recommended where high toughness is a primary requirement.

It is not uncommon for white fir to be described as brittle or brash as compared with other woods commonly used in house construction.

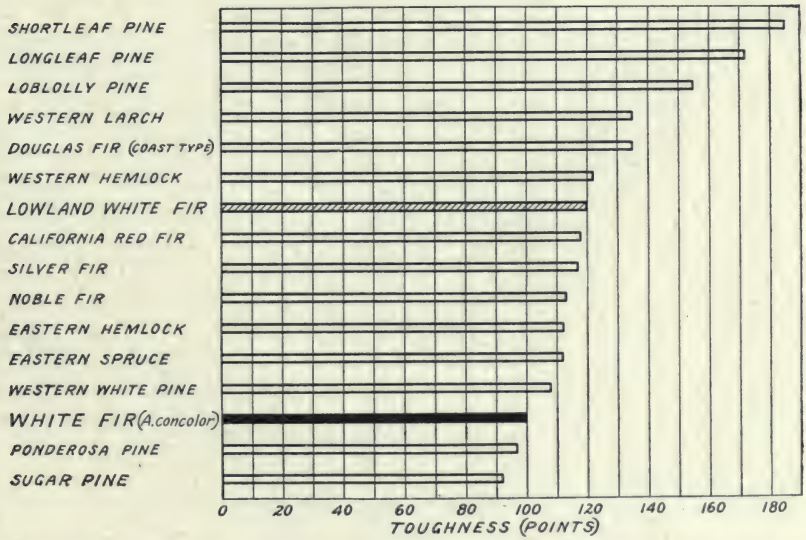



FIGURE 11.—Shock resistance or toughness of white fir (*Abies concolor*) compared with that of other woods. The comparison is for clear lumber. The loss in shock resistance resulting from such defects as knots and cross grain is especially high.

White fir is not so tough as the heavier softwoods, such as southern yellow pine, Douglas fir, or western larch. Such a description, however, is erroneous when the comparison is with the lighter softwoods (fig. 11). Lowland white fir is tougher and white fir (*Abies concolor*) not quite so tough as eastern hemlock and eastern spruce lumber. Of the species commonly sold in mixture with the white firs only alpine differs materially from the white firs in toughness. Alpine fir has less than two thirds the toughness of the white firs, and such a pronounced difference is bound to react unfavorably on the reputation of the white firs for toughness when alpine fir is sold in mixture with them.

The toughness of all lumber is greatly influenced by defects. A slope of grain of 1 inch in 10 inches will cause a loss of about one third in toughness. A large knot or a small amount of decay may readily reduce the toughness one half.

### STIFFNESS

There is considerable difference in the stiffness of lowland white fir and white fir (*Abies concolor*). Lowland white fir is a stiff wood being

almost as stiff as heavy softwoods like Douglas fir (coast type) and is stiffer than any of the lightweight softwoods (fig. 12). White fir is similar in stiffness to the lightweight softwoods. Its stiffness is about the same as that of eastern hemlock and eastern spruce, which are two species extensively used for joists and studs where stiffness is an important requirement.

Both the white fir (*Abies concolor*) and lowland white fir are stiff for their weight, but lowland white fir is outstanding. Of the principal species used for lumber only noble fir and silver fir can equal lowland white fir in this respect. The combination of stiffness and light weight of white fir is favorable to its use for joists, studding,

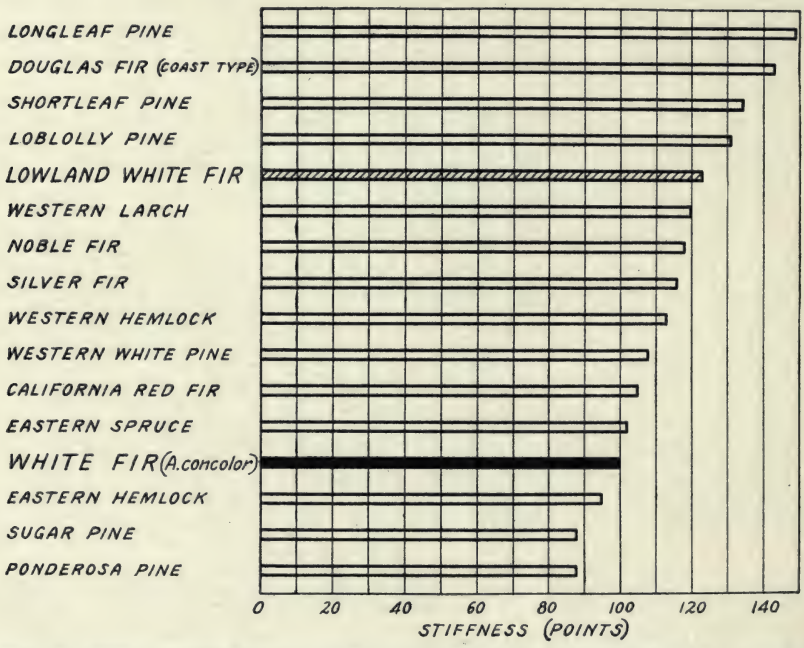



FIGURE 12.—Stiffness of white fir (*Abies concolor*) compared with that of other species. The comparison is for clear wood but applies also to any given grade of lumber almost as well, provided other things are equal.

and subfloors. All of the woods sold in mixture with white fir are more flexible than lowland white fir and all except alpine fir are stiffer than white fir (*A. concolor*).

Defects permitted in the sound commercial grades have little or no effect upon stiffness. The values in table 10 and figure 12 are therefore applicable to lumber almost as well as to the clear wood. An average value of stiffness for use in design is given in the table of working stresses under the heading Average Modulus of Elasticity (p. 52). The values for modulus of elasticity take into consideration species characteristics and peculiarities, and do not therefore check exactly with the stiffness values for the clear wood.

### HARDNESS

White fir is used for its softness rather than for its hardness (fig. 13). The two species of white fir have about the same hardness,

which is about the same as the hardness of ponderosa pine. They are softer than the hemlocks but harder than western white pine, northern white pine, or sugar pine. All of the other true firs, except California red fir, are softer than the white firs. Of the species that are at times sold in mixture with the white firs, California red fir, alpine fir, and western hemlock differ from them in hardness enough to have a practical significance. In uses where uniform hardness or softness is desired, such as in flooring, these three species may prove objectionable in mixture with the white firs—alpine fir because of its softness, and California red fir and western hemlock because of their hardness.

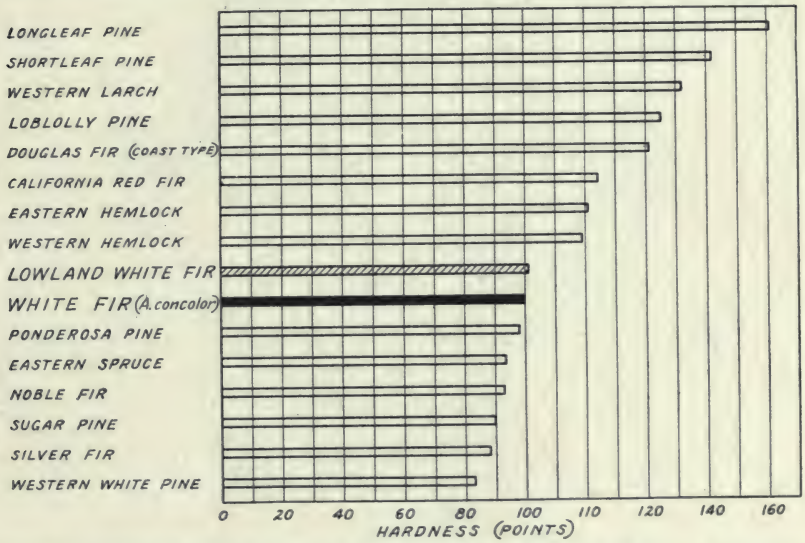



FIGURE 13.—Hardness of white fir (*Abies concolor*) compared with that of other woods. Comparison is applicable to all grades of lumber which contain only sound wood.

The softness of white-fir lumber is one of its greatest assets. It can be worked easily with hand tools. The carpenter and contractor like it because of the ease with which it is cut, sawed, and nailed enables them to put more of it in place in a day than they can of harder, less easily worked woods.

Softness is seldom a desirable property once the wood is in service or in place. Users are interested in the saving in cost of manufacture, fabrication, or construction because of the softness of white fir only insofar as these savings are passed on to them in reduced final costs. Softness is a requirement in a few uses of which drafting and bulletin boards are examples.

### SPLITTING RESISTANCE

White fir is easy to split with an ax. The resistance of lowland white fir to the splitting action of axes or wedges is about the same as that of eastern spruce. White fir (*Abies concolor*) is more difficult to split than lowland white fir, being about the same in splitting resistance as western hemlock and Douglas fir (coast type). The comparison in figure 14 is based on the results of tests in which wood is pulled apart by forces acting at right angles to the grain. The comparison can be used to judge the ease with which the woods can

be split into bolts or flitches and how well the wood will resist the splitting action of bolts or wedges. It is not a measure of the tendency to split in nailing, seasoning, or machining.

Splitting under the action of nails is influenced by hardness and uniformity of texture, as well as by splitting resistance. Lightweight, soft, uniform-textured woods usually split less in nailing than hard, heavy woods, with pronounced differences between summer wood and spring wood. White fir is soft, light, and fairly uniform in texture. In tests made at the Forest Products Laboratory Douglas fir (coast type), western larch, and western hemlock split more in nailing than white fir. Northern white pine splits less in nailing than white fir. White fir (*A. concolor*), because of its texture and splitting resist-

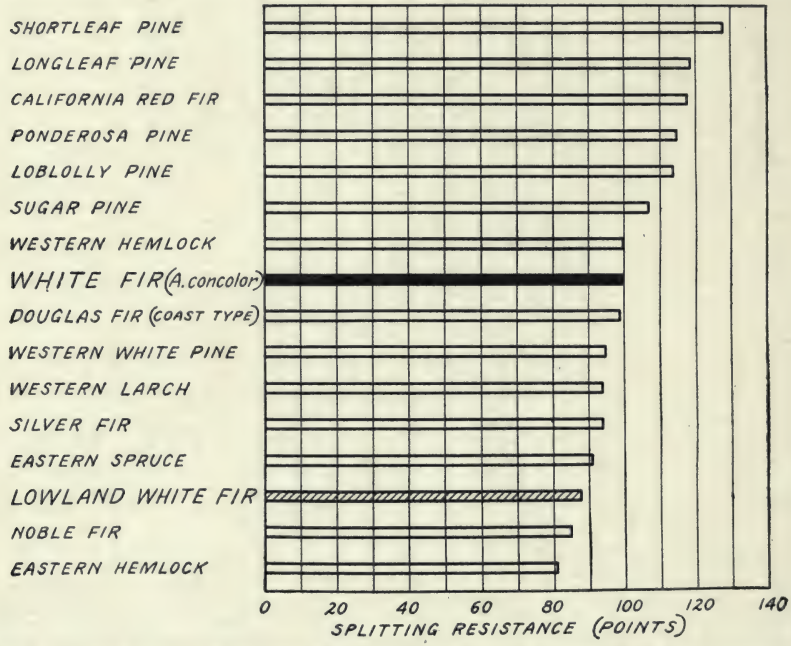



FIGURE 14.—Inherent splitting resistance of white fir (*Abies concolor*) compared with that of other woods.

ance, would be expected to split somewhat less when nailed than lowland white fir.

The splitting that occurs in seasoning and handling is best judged by the number and kind of splits found in the lumber as it is marketed. Splits result from a variety of causes, such as cupping, shake, seasoning methods, and handling, so that prediction based on analysis of properties is unsatisfactory. An actual tally of the splits in representative samples of the lumber of 14 of the principal commercial species showed white fir to have about the same number of splits as eastern hemlock, western larch, and western white pine. The splits were larger and more numerous than in ponderosa pine, Douglas fir (coast type), southern cypress, or northern white pine.

### NAIL-HOLDING POWER

The nail-holding power of white fir, though low, can meet ordinary-use requirements when nails are driven into the dry wood. The

average holding power of a single 7-penny cement-coated nail driven 1¼ inches into the side grain of dry lowland white fir was 166 pounds. Driven into white fir (*Abies concolor*) it was 190 pounds (*13*). Nails driven into green white fir lost about one fourth of the original holding power when the wood dried. All woods lose holding power when they dry after nailing. It is, therefore, poor practice to nail into green or wet white fir or any species which will dry later. Most of the trouble from loose boards and pulled nails can be traced to the use of wet wood or inadequate nailing. It is seldom caused by the inherent weakness of the species in nail-holding power.

The nail-holding power of white fir is low as compared with that of other woods commonly used in building construction. It is about three fourths to five sixths that of eastern hemlock and ponderosa pine and about one half that of longleaf pine. More or larger nails

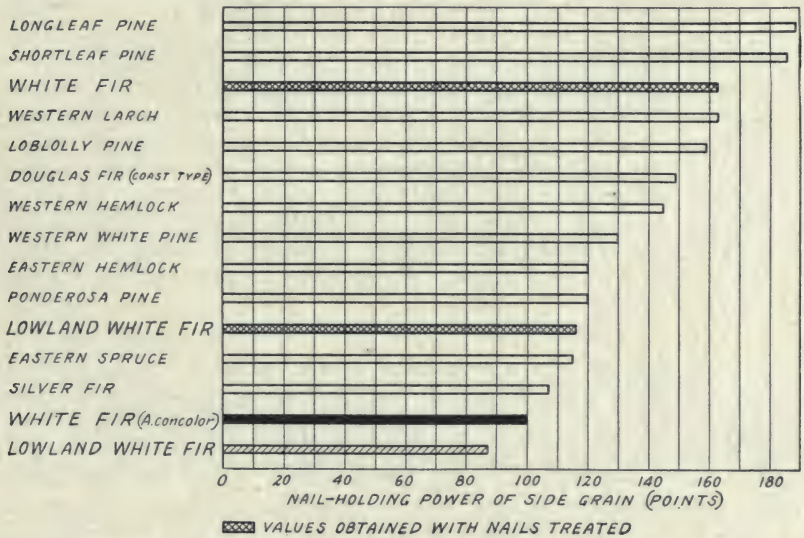



FIGURE 15.—Holding power of cement-coated nails driven into and pulled from dry, clear wood of white fir (*Abies concolor*) compared with that of other woods.

or nails of special design must, therefore, be used with the white firs to obtain holding power equal to that of the principal construction and container woods. The softness and uniform texture of the white firs usually permit the use of nails large enough to obtain the necessary nail-holding power without undue hazard from splitting. It is not, however, generally necessary to use a special type or to increase the size or number of the nails in subfloors, sheathing, and roofing boards fastened to white-fir framing in order to obtain satisfactory holding power.

The forest products laboratory has recently developed a simple chemical treatment[9] for nails that greatly improves their holding power (*14*). The chemically treated nails driven into white fir (*Abies concolor*) developed about two and one half times the holding power of smooth nails and about one and one third times the holding power of cement-coated nails (fig. 15). Such an increase makes whitefir-

[9] This treatment is covered by U. S. patent no. 1,911,421, which has been dedicated to the citizens of the United States and is available for use by any manufacturer without royalty charges.

nail-holding power with the treated nail about equal that of the best of the lightweight softwoods with the best of cement-coated nails, and probably equal to any of our native softwoods with plain nails. The treated nails have a corresponding increased holding power in other species.

## SUSCEPTIBILITY TO ATTACK BY DESTRUCTIVE AGENTS AND TO TREATMENT

### DECAY RESISTANCE

White fir (p. 2) is not suitable for use untreated where the decay hazard is high. Its resistance to decay is low. Based on service records and general experience the heartwood of white fir is classed with the heartwood of basswood, cottonwood, and other true firs in decay resistance.[10] Even where the decay hazard is moderate the average life is too short to justify the use of the species untreated. Where the decay hazard is low, such as in siding, subfloors, interior trim, studding, or joists, the wood will last indefinitely, for the fungi that cause decay cannot carry on their destructive work so long as the wood remains dry. Occasionally decay occurs in house framing, subflooring, or sheathing where there is no direct exposure to weather and the wood is apparently dry. The so-called dry rot is usually responsible for such occurrences. Dry-rot fungi can conduct water to dry wood from a distant source. Given a good preservative treatment the decay resistance of white fir is very satisfactory and the wood may then be used safely under conditions that favor decay.

### TREATING CHARACTERISTICS

Both the heartwood and sapwood of the white firs are very resistant to the penetration of preservatives. In this respect they have been found to be similar to Engelmann spruce (*10*). The absorptions, however, were found to be somewhat heavier, the end penetrations were heavier, and the preservative more concentrated in treated portions in lowland white fir than in Engelmann spruce. Either creosote or a water-soluble salt, such as zinc chloride, may be used in treating white fir. Service records obtained from ties used in arid regions indicate that considerable checking is to be expected in white-fir ties in the course of 4 or 5 years unless petroleum or fuel oil is used in combination with the creosote or zinc chloride. The petroleum oil greatly retards the checking and splitting. Penetration of from five eighths to three fourths of an inch can be obtained in the heartwood of lowland white fir and 2 inches or more can be obtained in the sapwood by any of the standard processes, if properly applied (*10*). Experience indicates that white fir (*Abies concolor*) can also be treated successfully under the same conditions, although no special tests have been made.

### WEATHERING

White fir, like all woods, weathers when exposed without paint or other protective coating. Unpainted white-fir (*Abies concolor*) panels exposed on a test fence at Madison, Wis., showed slight

[10] U. S. DEPARTMENT OF AGRICULTURE, FOREST SERVICE. COMPARATIVE DECAY RESISTANCE OF HEARTWOOD OF DIFFERENT NATIVE SPECIES WHEN USED UNDER CONDITIONS THAT FAVOR DECAY. U.S. Dept. Agr., Forest Serv. Forest Prod. Lab. Tech. Note 229, 2 pp. 1929. [Mimeographed.]

weather checking in about 3 weeks. At the end of a year the checking was marked. At the end of 4 years the weathering was more pronounced than in the cedars, southern cypress, and redwood, and about the same as in western white pine, northern white pine, sugar pine, and ponderosa pine, but not so marked as in eastern spruce or eastern hemlock. The change from smooth wood to weather-beaten wood takes place in about a year. The weathering is worse if the wood is exposed before it is thoroughly dried. Exposing partially seasoned white fir has in some localities caused the wood to acquire an unfavorable reputation for weathering. Weathering in white fir can be prevented by the application and maintenance of a good paint coating.

The white firs are unsuited for use as posts, piles, poles, ties, or in contact with the ground unless they are treated. Preservative treatment, however, adapts white fir to these and other uses for which they would otherwise be unsuited.

#### RESISTANCE TO ATTACK BY INSECTS, TERMITES, OR MARINE BORERS

White fir (p. 2) when used where it may be attacked by insects, termites, or marine borers should be treated with a preservative. In this respect it is similar to all of our commercial woods. While some of our native woods have a greater resistance to attack from such sources none is immune.

The high hazard created by the prevalence of termites and marine borers in parts of California presents an opportunity for the marketing of preservative-treated white fir. The cost of transporting white fir lumber from the mill to the region of high hazard is low because the haul is short. Little effort has been made to develop the market for white fir in these regions, probably because untreated white fir is unsuited for use in the region and because the mills cutting white fir do not have facilities for treating the lumber. The installation of treating plants either by white fir manufacturers or by others would open an additional market for the species.

### CHARACTERISTICS DEPENDING ON A COMBINATION OF PROPERTIES

#### SEASONING CHARACTERISTICS

Several of the large operators regularly kiln dry their white fir of the select grades and a few kiln dry a portion of their common grades. By far the greater part of the white-fir production, however, is seasoned in the yards. Degrade due to defects developing from shrinkage, especially surface checking, end checking, loosening of knots, and splitting, is greater than in the pines cut by the same operators.

#### AIR DRYING WHITE FIR

Table 11 shows the percentages of various defects developed in air drying white fir in a California yard in which drying conditions were representative of the average for white-fir producing districts of the State. The data are for material in standard 16-foot piles erected in May, June, and July, and taken down in August, September, and October. The period of drying was from 1 month to 4 months. The moisture content at final inspection varied among the different piles and with different thicknesses of material.

TABLE 11.—*Defects developed in air drying white fir (Abies concolor) in central California during summer* [1]

| Green grade | Thickness of material | Total [2] degrade | Types of defects found on degraded boards based on grade-volumes as piled [3] | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Check [4] | Split [5] | Loose knots | Checked knots, broken knots, knot holes | Warp | Broken in handling |
| | *Inches* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| C and Better | 1 | 22.4 | 8.8 | 13.7 | 0.4 | ---------- | 2.2 | 0.4 |
| | 1⅝ | 13.9 | 8.2 | 5.2 | ---------- | ---------- | 1.4 | .4 |
| | 2 | 18.9 | 19.6 | ---------- | ---------- | ---------- | ---------- | ---------- |
| No. 1 Common | 1 | 23.1 | 13.8 | 9.0 | 1.2 | 0.4 | .3 | ---------- |
| | 1⅝ | 15.9 | 5.8 | 4.9 | 3.0 | 1.2 | 4.2 | .4 |
| | 2 | 20.5 | 15.5 | 1.7 | 4.6 | ---------- | 2.3 | ---------- |
| No. 2 Common | 1 | 39.4 | 14.6 | 7.7 | 14.1 | 12.8 | 3.5 | .2 |
| | 1⅝ | 26.9 | 7.5 | 6.8 | 7.1 | 7.0 | 2.2 | .7 |
| | 2 | 34.2 | 33.1 | 6.5 | 8.8 | 13.0 | 3.0 | ---------- |
| No. 3 Common | 1 | 15.7 | 4.6 | 5.2 | 9.0 | 6.1 | .2 | .7 |
| | 1⅝ | 17.9 | 8.3 | 7.7 | 2.5 | 4.9 | 1.9 | 1.3 |
| | 2 | 22.3 | 23.1 | 12.5 | 1.9 | 4.1 | .6 | .4 |
| No. 4 Common | 1 | 5.1 | 1.7 | 4.2 | .4 | .7 | ---------- | ---------- |
| | 1⅝ | 14.3 | 5.0 | 10.6 | .2 | 2.1 | .9 | 1.4 |
| | 2 | 15.6 | 12.3 | 11.4 | ---------- | 2.0 | ---------- | ---------- |

[1] Based on 123,000 board feet studied by the California Forest Experiment Station.
[2] The amount of degrade from all causes at time of taking down the piles. The final moisture content ranged from 6 percent in the material seasoned for 4 months to 30 percent in the material seasoned 1 month. Much of the loss indicated here is recovered by subsequent remanufacture.
[3] Percentages denote total occurrence of a given defect regardless of other defects in same piece and therefore do not jointly total with column 3.
[4] Includes end, spiral grain, and surface checks.
[5] Includes end, spiral grain, and surface splits.

Surface and end checking, the principal air-drying defects in white fir, are brought about by the rapid drying of the surfaces and ends and the slow drying of the interior of the piece. When a green board with, say, 150-percent moisture content is placed in a seasoning pile, evaporation will begin immediately and will proceed at a rate governed by the temperature, humidity, and circulation of air within the pile. At 150-percent moisture content, the board is far above the starting point of shrinkage but it does not take long to reduce this 150-percent to 30-percent moisture content or less on the ends of the board if they are exposed to direct sunshine, a strong wind, or both. Within 2 or 3 days end checking may take place, though a cross section cut from the board a foot or two back from the ends may still show a moisture content of approximately 125 percent. This rapid drying of the exposed surfaces of the board results in surface and end checks. In the interior of a lumber pile, the faces and sides of the boards dry slower than at the exposed ends; nevertheless, if they dry much faster than the interior the same force comes into play that takes place on the ends, that is, the external shell of the boards will reach the shrinkage point, the wet interior will remain expanded and will resist the shrinkage stresses in the shell so that the shell must split, or surface check, at irregular intervals until the stresses are equalized. Knot loosening may take place long before the interior of the board reaches 20-percent moisture content because the knots naturally dry out faster through their exposed ends than the surrounding wood. If the knot is firmly intergrown it will check or split in shrinking instead of loosening itself from the board. From the foregoing, it becomes evident that white fir at 20-percent moisture content exhibits practically

as many of the principal drying defects as it does when dried to 10- or 12-percent moisture content.

Although there is little difference in pile degrade between 20-percent and 12-percent moisture content, nevertheless white fir depreciates badly in service if fabricated while green or only partially dry (20-percent moisture content). This is because each board is no longer a unit in itself free to complete its through-and-through shrinkage, but has become a rigidly nailed, glued, or doweled part of a larger, composite unit. Further, the board in the seasoning pile is held flat by the weight of the boards above it, and is therefore prevented from becoming severely warped or twisted, and in addition is enabled to complete its seasoning under much milder drying conditions than when exposed to unrestricted circulation and sunshine as part of the framework of a building under construction.

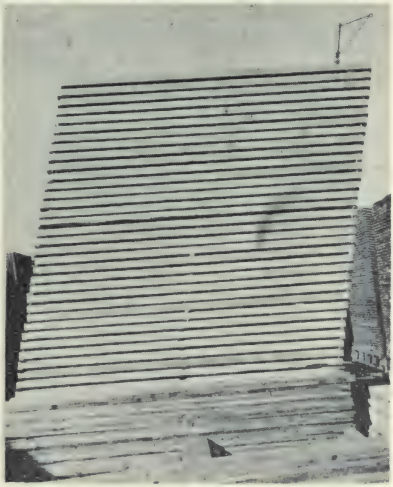


FIGURE 16.—White fir dimension 4 inches thick piled on stickers 1 inch thick to retard the drying rate so that checking will be reduced. This is ideal practice in hot, dry climates where too rapid evaporation will result in heavy degrade.

Present depreciation during the seasoning of white fir can be greatly reduced by more strict observance of sound seasoning practice. On established operations it is usually not feasible to relocate yards that are poorly situated, but much can be done to improve piling procedure and pile construction.

In the seasoning study from which the figures in table 11 were taken, 21.1 percent of the degraded C and better white fir had been fully exposed to the sun for 2 to 7 days while the pile was being erected. A truck load of white fir would be taken to the yard from the green chain and laid on stickers, 1 truck load being sufficient for about 7 courses. As C and Better of a particular thickness accumulated slowly at the sorting table, 4 or 5 days might elapse before another truck load would be ready for the yard. In the meantime, the top course last laid would check badly in the sun, the next course would check to a lesser extent, and even the third course would check slightly. The same procedure followed for every truck load, 6 or 7 in number, until the pile was built to a height of about 18 feet. The results are evident in table 11. An additional 15.6 percent of the degraded C and Better, white fir had been exposed either through lack of a pile roof during the entire drying period or because 2 or 3 days had elapsed between completion of the pile and the application of roof boards (figs. 16 and 17).

With proper piling and reasonable care in handling, there is ample evidence that white fir can be air dried to 10- or 12-percent moisture content with a depreciation in grade of 12 percent or less, equivalent to a depreciation in value of not more than 5 percent, mill run. The loss will be the same, at the time of unpiling, whether taken down at 18 to 20 percent or at 10-percent average moisture content. About one half of the loss in value can be recovered by simple trimming and

ripping. In remanufacturing to dimension, the increase in value is often more than that lost through seasoning degrade. The dry stock, if stored, shipped, or used at once, will undergo practically no further degrade, but stock at 18-percent moisture content or higher

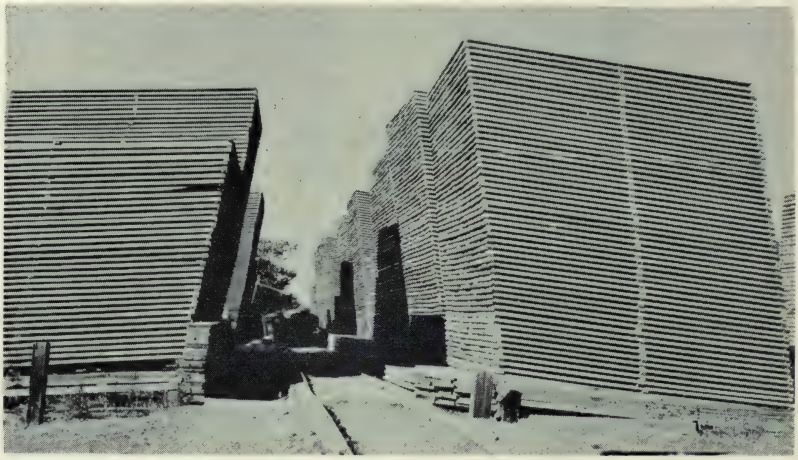


FIGURE 17.—White fir dimension planks piled for air seasoning with 1⅝-inch stickers. Drying is more rapid and degrade heavier than in figure 16. The piles illustrated are well constructed but lack roofs. When piles are left unroofed degrade is severe in the upper courses

will depreciate considerably more when stored, piled in a retail yard, or placed in use.

Some other factors (*6*, *7*) contributing to an increase in degrade are poor placement of stickers, careless handling of lumber, and cross piling of occasional boards.

### KILN DRYING OF WHITE FIR

A study of depreciation in commercially kiln-dried white fir (*Abies concolor*) was made in 1929 by the Forest Service at a California mill, the results of which are shown in table 12.

TABLE 12.—*Degrade in kiln drying 1⅝ by 8 inch white fir (Abies concolor)* [1]

| Green grade | Percentage by volume falling to lower grades before remanufacture | Percentage by volume after remanufacture, rough dry | | | | Loss (−) or gain (+) in final value.[2] Percent of original value |
|---|---|---|---|---|---|---|
| | | Raised in grade | No change in grade | Below grade | Waste [3] | |
| C and Better | 6.0 | ---------- | 97.5 | 2.0 | 0.5 | −1.5 |
| No. 1 Common | 10.0 | 5.0 | 85.5 | 8.0 | 1.5 | −2.0 |
| No. 2 Common | 10.0 | 4.5 | 89.5 | 4.5 | 1.5 | −1.2 |
| No. 3 Common | 3.0 | 15.5 | 79.5 | 1.5 | 3.5 | +.1 |
| No. 4 Common | 5.0 | 25.5 | 65.5 | 3.0 | 6.0 | −1.4 |
| Weighted average all grades | 6.15 | 11.4 | 82.4 | 3.4 | 2.8 | −.9 |

[1] Based on 20,103 board feet of mixed No. 4 Common and Better studied by the California Forest Experiment Station.

[2] Extra cost of trimming and ripping included as a loss.

[3] Waste in percentage of original green volume from trimming and ripping.

The kiln was of the compartment type with forced circulation. The schedule used was designed for rapid output rather than minimum degrade, nevertheless fair results were secured. The average moisture content was about 18 percent for all runs combined. Enough material of low moisture content was tallied to indicate little or no increase in the development of defects between 20-percent and 10- to 12-percent moisture content.

In general, the temperatures and humidities were left fairly constant throughout the period of drying. The average dry-bulb temperature was about 150° F. and the relative humidity between 41 and 50 percent. Drying time was from 128 to 152 hours, a charge being removed when an end-coated sample reached about 18-percent moisture content.

Drying schedules vary greatly among different mills. Practically all call for temperature and humidity changes correlated with elapsed time periods. Each schedule is based on the experience of the individual mill with its own equipment, hence what will work at one mill may give poor results at another. The only schedule that can be universally recommended must necessarily make allowance for variations in type of equipment. For a complete discussion of kiln-drying procedure and outlines of schedules, kiln operators are referred to the Kiln Drying Handbook (*22*).

### CAPACITY TO STAY IN PLACE

Capacity to stay in place is required in some degree by all uses of wood. It is one of the important requirements of interior trim, doors, window frames, and sash. It is also a requirement of rough uses, subfloors, sheathing, framing, and concrete forms, though not so important in these uses.

The properties that determine how well a wood stays in place are its shrinkage and tendency to warp. Shrinkage causes a change in dimension, warping a change in shape. Comparison of the shrinkage of white fir (*Abies concolor*) with that of a number of species is shown in figure 7. A numerical comparison of the tendency to warp cannot be made. Warping is caused by knots, cross grain, the difference in the shrinkage between radial and tangential directions, unequal shrinkage of heartwood and sapwood, and compression wood. No satisfactory method of evaluating the foregoing factors has yet been devised. An analysis of factors that influence the capacity of wood to stay in place indicates that white fir is satisfactory in this respect. Its shrinkage is low and it therefore swells and shrinks less than most commercial softwoods. The amount of compression wood in white fir is about the same as that in western white pine, which stays in place well. The frequency of occurrence of cross grain, which is responsible for most of the tendency to twist, and the proportion of heartwood and sapwood in white fir is not known. The difference in the shrinkage between the radial and tangential directions is large and is reflected in the tendency to check. White fir dimension is favorably known for its straightness, indicating that the capacity of the wood to stay in place is satisfactory for less exacting uses. The wood has also been used with satisfaction for more exacting purposes, such as interior trim. It is not suited for uses where the requirements are extremely exacting, such as in patterns.

The conflicting opinions among consumers regarding the tendency of white fir to stay in place are the result of differences in the degree of seasoning. To stay in place satisfactorily in any use the wood must be thoroughly seasoned. Most of the trouble experienced with white fir not staying in place can be traced to the use of green or partially dried lumber.

### GLUING CHARACTERISTICS

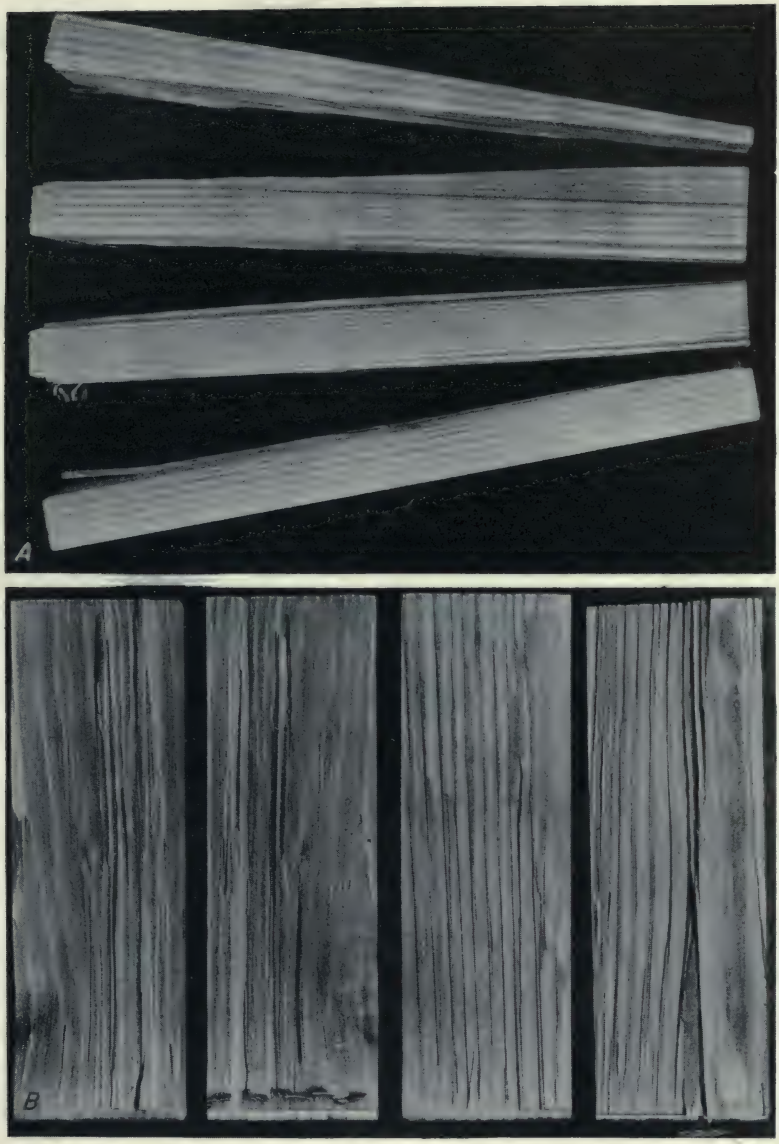
White fir (*Abies concolor*) is one of the easiest of our native species to glue (*23*). On joints made with animal, vegetable, or casein glue and then tested to failure, the failures occurred practically 100 percent in the wood (pl. 3). The joints developed on an average a shear strength of about 1,500 pounds to the square inch. The strength of the joints was about the same with all three glues and all the wood failures indicate that it was limited by the strength of the wood and not by that of the glue. Joints made with animal glue under poor conditions, which in many species result in starved joints, also failed in the wood so that their effective strength was as good as that of joints made under good gluing conditions. White fir (*A. concolor*) can therefore be glued satisfactorily under a wide range of conditions. The schedules developed at the Forest Products Laboratory and recommended for gluing white fir are shown in table 13. While all the tests were made on white fir (*A. concolor*) it is believed that equally good results can be obtained with lowland white fir, and the schedules of table 13 are recommended for use with it and the other true firs.

TABLE 13.—*Gluing schedules for white fir*

| Kind of glue | Proportion of glue to water by weight [1] | Glue spread | Temperature of the wood | Pressure | Closed assembly time [2] |
|---|---|---|---|---|---|
| | | *Pounds per 1,000 square feet* [3] | °*F.* | *Pounds per square inch* | *Minutes* |
| Animal [4] | 1–2¼ | 60–65 | 70 | 100–150 | 0–1 |
| | 1–2¼ | 65–70 | 80 | 100–150 | 1–5 |
| | 1–2¼ | 70–75 | 90 | 100–150 | 3–20 |
| | 1–3 | 70–75 | 90 | 100–150 | 5–20 |
| Casein [5] | 1–2 | 60–70 | 70–90 | 100–150 | 0–15 |
| | 1–2⅛ | 70–80 | 70–90 | 100–150 | 3–20 |
| Vegetable [5] | 1–2⅛ | 60–70 | 70–90 | 100–150 | 0–20 |
| | 1–2¼ | 70–80 | 70–90 | 100–150 | 1–25 |

[1] The recommended proportions of glue and water are suitable for both lumber and veneer gluing, but ordinarily it is better to use a thicker glue mixture with lumber than veneer.
[2] Wood pieces laid together as soon as spread with glue.
[3] Weight of wet glue mixture.
[4] An animal glue equivalent to about No. 12 in the National Association of Glue Manufacturers grades. Other grades may be used if suitable adjustment in the proportions of glue and water are made.
[5] Some glues require more or less water than shown here in order to obtain the same consistency of mixture.

Little advantage has been taken of the excellent gluing characteristics of the white firs. The wood can be used for core stock, laminated construction, furniture, or other uses where good glue joints are an important requirement. Only comparatively small quantities, however, have been used for these purposes.




GLUED LAMINATIONS OF WHITE FIR SHOWING TYPE OF FAILURE RESULTING IN TEST.

A, Side view showing glue line, all four glue joints still intact. B, Surface view showing failure occurs in wood rather than glue.

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WHITE FIR PAINTED PANELS AFTER 7 YEARS' EXPOSURE AT MADISON, WIS.

The panels received three coats of standard mixed paint when exposed in 1924. The portion to the left of the black line was repainted in 1927. The top panel is flat grain and the bottom edge grain. The panel shows that white fir holds paint well, especially on edge-grained surface.

### PAINTING AND FINISHING CHARACTERISTICS

White fir (p. 2) holds paint well. In this respect it is classed with the hemlocks, spruces, and ponderosa pine. It holds paint better than the heavier, harder, and less uniform-textured woods, such as southern yellow pine and Douglas fir, but not so well as the lighter-weight cedars, redwood, and more uniform-textured white pines. White fir is nonresinous and therefore does not exude resin beads to spoil paint finishes; neither does the paint peel off the knots or become discolored as it does with resinous woods.

The Forest Products Laboratory is studying the painting characteristics of white fir and 17 other native softwoods. The study (*3*) has been in progress about 8 years and is conducted on panels exposed on test fences at widely scattered points throughout the United States. Plate 4 shows the results of 7 years' exposure of the white, fir panels on a test fence at Madison Wis. White fir when fully exposed to the weather ordinarily will require repainting in about 3 years. The time, however, varies greatly with exposure, climatic conditions, with edge-grained or flat-grained material, and with quality of paint. If the surfaces facing south are shaded by buildings or trees, repainting may not be needed oftener than once every 5 or 6 years in a climate like that in New England and the Lake States. In a climate where there is little rain, long periods of low humidity, and much sunshine, as in parts of California and the Southwest, unprotected southern exposures may require repainting every year or two.

White fir should be closely watched for weather checking. At the first sign of fine checks or breaks in the paint coat it is time to repaint even though the general appearance is still good. White fir has a decided tendency to weather-check when unprotected and directly exposed. The checks quickly become long and wide and may extend through the board. Maintenance of a good paint coat will prevent checking, and since white fir holds paint well it is not difficult to maintain the desired smooth, even appearance of painted surfaces. Edge-grained white fir holds paint much better than flat-grained material (pl. 4). Paint will prevent the weathering and checking of edge-grained white fir from one and one half times to more than twice as long as it will on flat-grained white fir, depending on climate. Very little edge-grained white fir is cut and it sells at a higher price than flat-grained material; edge-grained siding and other exterior trim will more than repay the difference in initial cost through lower painting maintenance.

The durability of paint on white fir can be increased a year or more by applying a priming coat of aluminum paint (*4*). A 3-coat job consisting of 1 coat of aluminum primer and 2 coats of light-colored paint costs little more than a standard 3-coat job but lasts longer. An aluminum primer coat on white fir makes it easier to keep the wood protected and thus decreases the checking and splitting hazard. Permanent protection from checking and splitting, however, can only be obtained by good maintenance.

No painting study directly applicable to interior conditions has been made on white fir. The suitability of the wood for enamel and natural finishes must therefore be judged by the results obtained in exterior tests, the figure and texture of wood, and the lack of resins and other extractives in the wood. The figure of the wood, especially in flat-grained material, is sufficiently pronounced to adapt white fir

to natural or stained finishes. Finish of the types required for interior trim of houses is readily obtained and easily maintained. White fir should give good service with high-class paint and enamel finishes. It has no resin to stain or discolor the paints, the grain is not sufficiently pronounced to make it difficult to cover, nor is it likely to rise under the conditions to which interior trim is subjected. Grain raising occurs principally on the pith side of flat-grained boards. Enamel and high-class paint finishes should therefore be applied to the face nearest the bark. Manufacturers can do much to prevent the occurrence of raised grain by not finishing pattern stock on the pith face. Repainting will ordinarily be required because of soiling rather than because of inferior paint-holding by the wood. The paint-holding characteristics of white fir are adequate to meet the requirements of interior trim.

No wet wood will hold paint satisfactorily. Surfacing while wood is still green or dressing with dull planer knivers causes the grain to rise, which is especially objectionable in interior trim that is either to be enameled or given a natural or stain finish. Most painting and finishing troubles with white fir can be traced to one of these causes, or to applying paint to the pith side of flat-grained boards. The trouble is not inherent in the species and white fir should not be condemned for it, for properly manufactured and seasoned white fir can be satisfactorily painted or finished.

### EASE OF WORKING

The effort required to cut, saw, and shape wood depends on the combination of softness, straightness of grain, and uniformity of texture. White fir has a favorable combination of these properties; it is soft, straight-grained, and fairly uniform in texture. The wood is therefore easy to cut, saw, and shape. In this respect it is easier to work than Douglas fir but not so easy as the soft pines. The ease with which it is cut, sawed, and nailed, combined with light weight, tends to speed construction and is responsible for much of the popularity of the white firs with the builders of small houses.

Hard, uniform-textured wood can be dressed and sanded to a smoother surface than soft nonuniform-textured wood. The texture and hardness of white fir are such that it can be dressed to a surface smooth enough for ordinary paint work. It can be sanded to a surface satisfactory for natural finishes. Such surfaces, however, are more difficult to obtain than with harder woods or wood with more uniform texture. The wood cannot be dressed satisfactorily when green, for it then tends to fuzz.

## CHEMICAL PROPERTIES

The basic chemical properties of white-fir wood differ little from those of other softwoods. Because of the lack of extractives white fir has no special chemical possibilities.

Little is known of the acid resistance of white fir. No recommendation can therefore be made for its use for purposes requiring this property.

### FIRE RESISTANCE

Differences in the fire resistance of species are commonly over emphasized (*24*). Differences within species resulting from oil, density, and resin are as significant as differences between species.

When high fire resistance is desired and untreated wood must be used, the wood should be selected for low resin and oil content and high density. In such a selection the absence of oil and resins in white fir entitle the species to consideration.

## GRADES AND THEIR CHARACTERISTICS

White fir (p. 2) from California and the Inland Empire is graded under the rules of the Western Pine Association (*30*). These grades

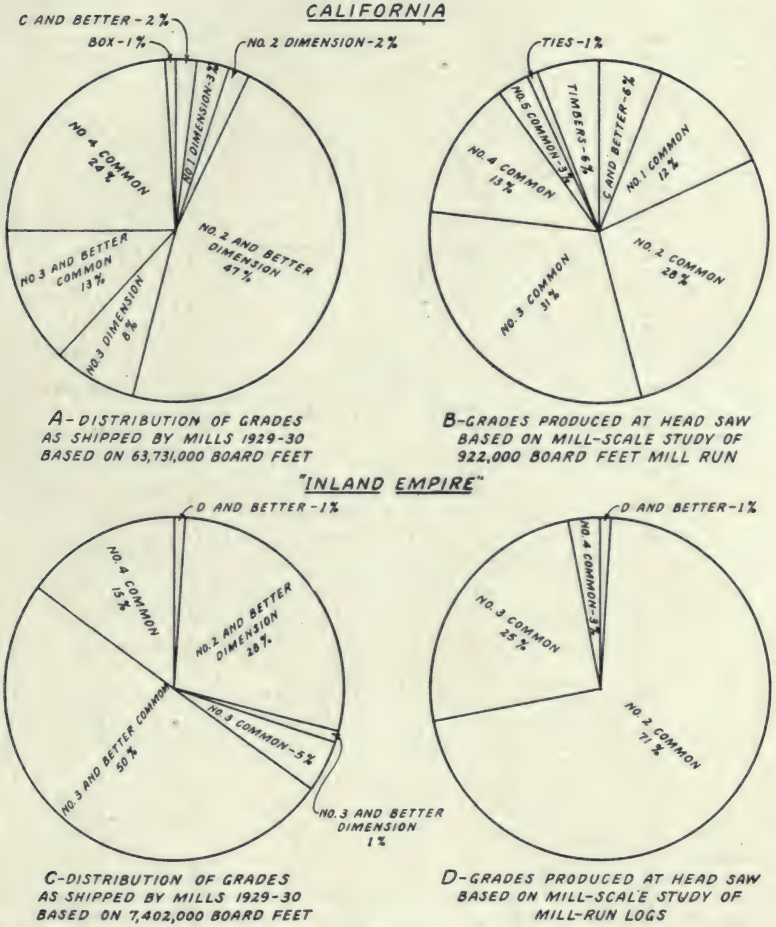

CALIFORNIA
C AND BETTER - 2%
BOX - 1%
NO. 2 DIMENSION - 2%
NO. 1 DIMENSION - 3%
NO. 4 COMMON 24%
NO. 2 AND BETTER DIMENSION 47%
NO. 3 AND BETTER COMMON 13%
NO. 3 DIMENSION 8%
A - DISTRIBUTION OF GRADES AS SHIPPED BY MILLS 1929-30 BASED ON 63,731,000 BOARD FEET
TIES - 1%
NO. 5 COMMON - 3%
TIMBERS - 6%
C AND BETTER - 6%
NO. 1 COMMON 12%
NO. 4 COMMON 13%
NO. 2 COMMON 28%
NO. 3 COMMON 31%
B - GRADES PRODUCED AT HEAD SAW BASED ON MILL-SCALE STUDY OF 922,000 BOARD FEET MILL RUN
"INLAND EMPIRE"
D AND BETTER - 1%
NO. 4 COMMON 15%
NO. 2 AND BETTER DIMENSION 28%
NO. 3 AND BETTER COMMON 50%
NO. 3 COMMON - 5%
NO. 3 AND BETTER DIMENSION 1%
C - DISTRIBUTION OF GRADES AS SHIPPED BY MILLS 1929-30 BASED ON 7,402,000 BOARD FEET
D AND BETTER - 1%
NO. 4 COMMON - 3%
NO. 3 COMMON 25%
NO. 2 COMMON 71%
D - GRADES PRODUCED AT HEAD SAW BASED ON MILL-SCALE STUDY OF MILL-RUN LOGS

FIGURE 18.—Comparison of distribution of grades of white fir as shipped from mills and as cut at the head saw: *A*, The bulk of the California cut of white fir is sold as Dimension. Much of the select material is marketed with the Commons. *B*, The grades obtained from the mill run of white fir logs in California. Direct comparison cannot be made with grades shown in *A*, for Common grades are largely remanufactured into Dimension grades after seasoning. *C*, The bulk of Inland Empire cut of white fir is sold as 1-inch Common lumber in contrast with the California cut (*A*), which is sold as Dimension. *D*, Grades of white fir obtained from mill-run logs in the Inland Empire. A comparison with *B* shows the larger yield of higher grades from the larger and clearer California white fir (*Abies concolor*). Comparison with *C* shows that shipments do not reflect what the average log will produce with good cutting practice.

are theoretically the same as the pine grades of this association, but because white fir yields too small a proportion of some grades to justify their segregation certain grades are combined that are not

combined in the pines. The standard grading rules (*30*), however, do not describe the combined grades in which white fir is marketed.

The practice of combining grades differs considerably in California and the Inland Empire (fig. 18), because of the characteristic differences in white fir trees in the two regions. The larger trees of the central-California pine region produce a greater percentage of select grades than the smaller trees found in the northern part of the region and in the Inland Empire. A grade of C and Better is commonly marketed by the California mills and D and Better by the other white fir producers. D select is also obtainable from the California mills, though material of this grade is usually made into pattern or No. 1 Dimension. Some California mills combine the first two common grades as No. 2 and Better Common instead of the first three common grades as No. 3 and Better Common. Practice in the two regions also differs in that white fir from California is marketed largely as dimension; that from the Inland Empire as 1-inch Common boards (fig. 18). The difference in the grades from the two regions is sufficient to warrant a separate discussion.

The grading rules (*30*) describe the grades by listing a number of typical examples under definitions that give the general characteristics of the grade. Such limitations cannot cover all the possible types and variations to be found in lumber of any grade. The typical examples are not repeated here. Instead, the grades are described by quoting the definitions from the grading rules and presenting a detailed record of the defects found in a study of the grades as marketed in 1928 and 1929.

Tables 14 and 15 show the practice of combining grades in the two producing regions and also the range of thicknesses most commonly sold in each grade. Periodic or annual summaries of white fir sales by widths in the Dimension grades or by patterns in any grade, such as baseboards, ceiling, and shiplap, are not kept by California mills, and cannot therefore be reported on a quantitative basis.

TABLE 14.—*Distribution by grades and sizes of white fir shipped by several California mills in 1929–30* [1]

| Grade | Thickness [2] | Widths | Percentage of total | Grade | Thickness [2] | Widths | Percentage of total |
|---|---|---|---|---|---|---|---|
| | *Inches* | *Inches* | | | *Inches* | *Inches* | |
| C and Better | All | All | 1.56 | No. 3 and Better Common | 1 1/16 | All | 0.07 |
| No. 1 Dimension | 1 9/16 | do | 1.50 | | 1 1/16 | 4 and 6 | .08 |
| | 1 5/8 | do | .08 | | 1 1/16 | 8 and 10 | .27 |
| | 1 3/4 | do | .19 | | 1 1/16 | 12 | .54 |
| | 1 7/8+ | do | 1.46 | | 1 | All | .75 |
| No. 2 Dimension | 1 9/16 | do | 2.45 | | 1 | 4 and 6 | 2.94 |
| | 1 5/8 | do | .01 | | 1 | 8 and 10 | 2.35 |
| | 1 3/4+ | do | .02 | | 1 | 12 | 1.16 |
| No. 2 and Better Dimension | 1 9/16 | do | 40.00 | No. 4 Common | 1 1/4+ | All | 4.50 |
| | 1 5/8 | do | 2.03 | | 1 1/16 | do | .37 |
| | 1 3/4 | do | 3.13 | | 3/4 | do | .35 |
| | 1 7/8+ | do | 2.45 | | 1 | do | 14.32 |
| No. 3 Dimension | All | do | 7.85 | | 1 1/4+ | do | 8.53 |
| | | | | Box | All | do | 1.04 |

[1] Based on 63,731,000 board feet.
[2] The Dimension thicknesses are actual, the Common nominal.

TABLE 15.—*Distribution by grades and sizes of white fir shipped by Western Pine Manufacturers' Association from Inland Empire in 1929–30* [1]

| Grade | Thickness [2] | Widths | Percentage of total | Grade | Thickness [2] | Widths | Percentage of total |
|---|---|---|---|---|---|---|---|
| | *Inches* | *Inches* | | | *Inches* | *Inches* | |
| D and Better | 1 | All | 1.01 | No. 3 and Better Common | 1¼, 1½, 2 | All | 3.03 |
| No. 1 and No. 2 Common | 1 | 6 | .08 | | 1 1/16 | do | 1.24 |
| | 1 | 8 | .05 | No. 1 Dimension | 1 9/16 | do | .13 |
| | 1 | 10 | .02 | No. 2 and Better Dimension. | 1 9/16 | do | 27.74 |
| | 1 | 12 | .11 | No. 3 and Better Dimension. | 1 9/16 | do | 1.01 |
| No. 3 Common | 1 | 4 | .23 | No. 4 Common | All | do | 14.69 |
| | 1 | 6 | .81 | | | | |
| | 1 | 8 | 2.07 | | | | |
| | 1 | 10 | 1.05 | | | | |
| | 1 | 12 | 1.05 | | | | |
| | 1 | 4 | 3.20 | | | | |
| No. 3 and Better Common | 1 | 6 | 10.37 | | | | |
| | 1 | 8 | 13.68 | | | | |
| | 1 | 10 | 10.37 | | | | |
| | 1 | 12 | 8.06 | | | | |

[1] Based on 7,402,000 board feet.
[2] The Dimension thicknesses shown are actual, the Common nominal.

## SELECT GRADES

### C SELECT AND BETTER

C Select and Better consists of the C Select grade and all the better products of the log. The grading rules (*30*) for C Select pine state: "This grade is primarily based on the idea of furnishing a high-class paint finish." The examples cited in the rule book show that a few pin knots, a few small knots firmly set, minor pitch pockets, and occasionally rough millwork on the back are admitted provided these defects are not in serious combination in the same piece, also various degrees of stain. Stain is found so seldom in white fir, however, that there is no need of describing the kinds and amounts of discoloration admitted in C Select or C and Better grade.

On the whole, C and Better white fir as now shipped is of high quality (pl. 5, *A*). Sample lots inspected in California frequently contained 50 percent or more of pieces that would grade B and Better under the pine rules (also known as 1 and 2 Clear).

The defects found in a study of 1,500 board feet of 1- by 8-inch C and better white fir are shown in table 16.

TABLE 16.—*Defect found in C and Better white fir from California* [1]

| Defect | Percentage of boards having defect | General character of defect in C and Better |
|---|---|---|
| Knots | 41 | Average size 0.41 inch, 89 to a thousand board feet. About three fourths of the knots were ½ inch or smaller. Largely intergrown and encased and a few loose. |
| Checks | 13 | Mostly small surface checks, none through. |
| Wormholes | 8 | All pinholes. |
| Stain | 5 | All light. |
| Torn grain | 6 | All slight. |
| Dark streaks | 3 | Small and medium. |
| Splits | 1 | All short. |

[1] Based on study of 1,500 board feet of 1- by 8-inch boards by the Forest Products Laboratory.

Defects averaged one to every 7 board feet; knots comprised nearly two thirds of the total. Seasoning defects, checks, stain, and splits were all present, but torn grain was the only manufacturing defect. Only knots and checks occurred in more than 10 percent of the pieces. Wormholes and dark streaks were the only special features of this grade as distinguished from most softwoods. Clear faces were found in 40 percent of the pieces.

### D SELECT AND BETTER

D Select and Better grade is produced principally by the mills in the Inland Empire. The mill run of white fir logs in the Inland Empire produces such a small percentage of lumber higher than D Select grade that it does not pay to segregate it.

Practice varies in California in respect to the D Select grade. Some mills make no effort to segregate anything between No. 1 Common and C and better, others carry D Select with all the better products of the log under the name D and Better, and still others include D Select with No. 3 Common and Better and segregate the stock later if orders for D Select are received. If there is no special demand for D Select it may be made into pattern, No. 1 Common, or No. 1 Dimension.

The grade consists of D Select and all the better products of the log (pl. 5, *B*). Mill-scale studies, however, indicate that the grade contains little lumber better than the D Select grade. The description of D Select grade in the grading rules (*30*) is:

> This grade of lumber belongs between the higher finishing lumber and the common grades, and partakes somewhat of the nature of both. Many pieces have a finish appearance on one side only, the backs showing numerous or very serious defects. A type often placed in this grade is a high line of piece requiring a cut to eliminate a knot hole or other defect too serious to go into finish work.

A study of 1,500 board feet of D and Better at two mills in the Inland Empire showed it to have one defect to every board foot; slightly over two thirds of the defects were knots. Checks were next commonest with 26 percent occurrence while the other seasoning defects, stain and splits, were of little consequence. Holes and torn grain followed check in frequency of occurrence. The defects were all in minor degrees, except for some loose and broken knots. Only the first five defects listed in table 17 occurred in more than 5 percent of the pieces. Clear faces were found in 2 percent of the pieces.

TABLE 17.—*Defects found in D and Better white fir from the Inland Empire* [1]

| Defect | Percentage of pieces having defect | General character of defect in D and Better |
|---|---|---|
| Knots | 92 | Average size 0.30 inch, 636 to a thousand board feet About 10 percent larger than ½ inch, a few broken and loose. |
| Dark streaks | 52 | Small and medium. |
| Checks | 26 | Mostly end checks and small checks. |
| Holes (not through) | 19 | Caused by picaroons or dogs. |
| Torn grain | 12 | Chiefly slight and medium. |
| Stain | 5 | All light. |
| Splits | 4 | All short and medium. |
| Skips | 4 | All slight. |
| Burn | 2 | Small. |
| Shake | 2 | Slight. |
| Wane | 1 | All slight. |
| Wormholes | 1 | All pinholes. |

[1] Based on a study of 1,500 board feet of 1- by 8-inch boards by the Forest Products Laboratory.

### COMMON GRADES

The grading rules (*30*) contain specifications for five common grades of lumber. White fir logs from both California and the Inland Empire yield some lumber of all five grades (tables 14 and 15). Neither region, however, makes a practice of marketing five grades of white fir commons.

Nearly all the mills ship Nos. 1, 2, and 3 Common white fir invoiced as No. 3 and Better Common. No definite specifications are set up as to the approximate proportion of each grade in the mixture. This will vary among different mills depending on the run of logs cut. In the California pine region, No. 3 and Better Common consisted, roughly, of about 50 percent No. 3 Common, 35 percent No. 2 Common, and 15 percent No. 1 Common. In the Inland Empire it consisted of about 50 percent No. 2 and 50 percent No. 3 Common. Some mills ship a grade of No. 1 and No. 2 Common mixed, and occasionally orders are filled for No. 3 and No. 4 Common mixed.

Any individual common grade of white fir is obtainable at mills that cut a high percentage of white fir, and as time goes on it will undoubtedly become more common practice to market each grade separately at the sawmill. No information is at hand to indicate the trend of the demand for separate common white fir grades. There follows a description of the five common grades.

#### NO. 1 COMMON

The amount of No. 1 Common produced from white fir is small. In the Inland Empire the yield of this grade is not sufficient to justify its segregation. A California mill scale study indicates that between 11 and 12 percent of the mill run was graded as No. 1 Common. The mill at which the study was conducted, however, was not separating D Select from the common grades. Later inspection after seasoning indicated that about one half of the No. 1 Common would qualify as D Select. Table 16 indicates that whatever the production no appreciable amount of No. 1 Common white fir is sold as such by California mills. The grade of No. 1 Common white fir is, therefore, of little importance.

The grading rules (*30*) define No. 1 Common as:

> No. 1 Common includes all sound, tight-knotted stock with the size of the knot the determining factor of the grade.
>
> Light pitch, very small pitch pockets or season checks, or equivalent small defects and blemishes, are admissible.
>
> Light stain covering the entire face is admissible in otherwise high line pieces.
>
> This grade is of a character that fits it for shelving, cornice, and all uses where best quality and appearance of common lumber is required.

The general appearance of the grade is shown in plate 6, *A*.

#### NO. 2 COMMON

Very little white fir is sold as No. 2 Common. The white fir logs produce a high percentage of No. 2 Common in both California and Inland Empire, but it is sold as No. 2 and Better, or No. 3 and Better Common, or is remanufactured into dimension.

The grading rules (*30*) define No. 2 Common as:

> Subject to the same general inspection as No. 1 Common, except that coarser and larger knots, not necessarily sound, or their equivalents, form the basis of inspection.

Some of the most common types of knots admissible in this grade are large knots, branch knots, checked knots, and those not firmly set in the piece. Other defects common to this grade are season checks, heart shake, heart pith, pitch, pitch pockets, slight traces of firm rot, and occasional wormholes. No serious combination of the above defects is admissible in any one piece.

The pitch defects permitted by the grading rules do not normally occur in white fir. Much of the lumber contains dark streaks, especially that from the Inland Empire. Dark streaks are not a defect in common grades. The general appearance of the grade is shown in plate 6, *B*.

A detailed study of the defects found in No. 2 and Better Common was made at a California mill. The defects found in the grade are shown in table 18. The grade was sound, but not tight. There were on the average 10 defects to every 10 board feet.

TABLE 18.—*Principal defects found in No. 2 and Better Common white fir from California* [1]

| Defect | Percentage of pieces having defect | General character of defect in No. 2 and Better Common |
|---|---|---|
| Knots | 92 | Average size 0.71 inch, 849 to a thousand board feet, very few larger than 1½ inches. Loose knots in 30 percent and knot holes in 3 percent of pieces. |
| Checks | 16 | Mostly small surface checks and end checks, some through. |
| Wormholes | 7 | All pinholes. |
| Splits | 4 | Mostly medium, rest short. |
| Stain | 4 | Mainly light, rest medium. |
| Shake | 3 | All types. |
| Wane | 2 | All slight. |
| Decay | 1 | All incipient. |
| Pith | 1 | Small amounts. |

[1] Based on a study of 1,300 board feet of 1- by 8-inch boards by the Forest Products Laboratory.

### NO. 3 COMMON

No. 3 Common is marketed principally in the mixture of No. 3 and Better Common. Over one half of the white fir cut in the Inland Empire is sold in these grades. The yield of No. 3 Common white fir in California is larger than the yield of any other grade, but much of it is remanufactured into dimension.

The following description is quoted from the grading rules (*30*):

The grade of No. 3 Common takes in much of the lower product of the log and although the appearance of a part of the stock is coarse it is a good general utility grade having a wide variety of uses.

Some of the defects common to this grade are: Large, loose or unsound knots, large branch knots, occasional knot holes, large wormholes, season checks, pitch and pitch pockets, skips and roller splits, some red rot, considerable heart shake, and any amount of stain.

Very little stain is found in white fir.

"A serious combination of the above defects is not admissible in any one piece."

A detailed study of the defects characteristic of No. 3 Common was made in California and the Inland Empire on No. 3 and Better Common (tables 19 and 20). In California the defects numbered 12 to every 10 board feet; in the Inland Empire 24 to every 10 board feet. In general the lumber from both regions is low grade, having numerous defects, some of which are serious in themselves and others

serious in combinations. The general appearance of the No. 3 Common grade white fir as produced in California is shown in plate 6, *C*.

TABLE 19.—*Principal defects found in No. 3 Common white fir from California* [1]

| Defect | Percentage of pieces having defect | General character of defect in No. 3 Common |
|---|---|---|
| Knots | 98 | Average size 0.88 inch, 1.059 to a thousand board feet. About 3 percent are larger than 1½ inches, holes and loose knots common. |
| Checks | 28 | Half-through checks. |
| Wormholes | 9 | Mainly pinholes, rest chiefly medium. |
| Decay | 8 | Half advanced. |
| Splits | 7 | Mostly medium, rest short. |
| Stain | 3 | All light. |
| Shake | 3 | All types. |
| Wane | 2 | Chiefly slight. |

[1] Based on a study of 7,600 board feet of 1- by 8-inch boards by the Forest Products Laboratory.

TABLE 20.—*Principal defects found in No. 3 and Better Common white fir from the Inland Empire* [1]

| Defect | Percentage of pieces having defect | General character of defect in No. 3 and Better |
|---|---|---|
| Knots | 100 | Average size 0.46 inch, 2,163 to a thousand board feet. Less than 1 percent are larger than 3 inches, loose knots and holes common. |
| Checks | 38 | Chiefly minor degrees, a few through. |
| Splits | 25 | Mostly short and medium, very few long. |
| Decay | 6 | Mostly incipient. |
| Stain | 5 | All light. |
| Pith | 5 | Mostly small amounts. |
| Shake | 4 | All types. |
| Wane | 4 | Slight and medium. |
| Wormholes | 2 | All pinholes. |

[1] Based on a study of 5,800 board feet of 1- by 8-inch boards by the Forest Products Laboratory.

### NO. 4 COMMON

No. 4 Common is an important grade of white fir. It is produced and sold both in the Inland Empire and in California. Although it is occasionally combined with No. 3 Common it is usually sold alone.

The following description of the grade is quoted from the grading rules (*30*):

> The defects common to this grade are much the same as those found in No. 3 Common but exist in more serious combination or to a greater degree.
>
> Knot holes, red rot, massed pitch, excessive heart shake, and heavy skips in dressing are some of the serious defects admissible in this grade. Other types are extremely coarse-knotted, waney, badly split, or badly checked pieces.

The general appearance of the grade is shown in plate 6, *D*.

A detailed study of the defects in the grade made at 2 mills in the Inland Empire showed that the grade had, on the average, 28 defects to every 10 board feet, many of them serious in themselves or serious when in combinations (table 21). Bad knots, through checks, long splits, and advanced decay were usually the determining defects.

TABLE 21.—*Principal defects found in No. 4 Common white fir from the Inland Empire* [1]

| Defect | Percentage of pieces having defect | General character of defect in No. 4 Common |
|---|---|---|
| Knots | 100 | Average size 0.48 inch, 2,300 to a thousand board feet, a few over 3 inches, loose knots and holes very common. |
| Checks | 59 | Nearly one fifth through checks. |
| Splits | 41 | About one fourth long. |
| Decay | 17 | Nearly one fourth advanced. |
| Stain | 14 | All light. |
| Pith | 8 | Mostly small amounts. |
| Wane | 7 | Slight and medium. |
| Wormholes | 6 | Chiefly pinholes. |
| Shake | 4 | All types. |

[1] Based on a study of 2,100 board feet of 1- by 8-inch boards by the Forest Products Laboratory.

### NO. 5 COMMON

The No. 5 Common grade is of small importance in white fir. Its value is too low to permit its being transported to markets at any great distance from the mill. Some mills use the grade in the manufacture of boxes, boards for grain cars, and similar articles, others sell the grade locally for rough and temporary uses, and still others send it to the slasher.

The grading rules (*30*) state:

> No. 5 Common is the lowest recognized grade and admits all defects known in lumber, provided the piece is strong enough to hold together when carefully handled.

### DIMENSION AND TIMBER GRADES

The grading rules (*30*) describe three dimension and timber grades; namely, No. 1, No. 2, and No. 3 Dimension and Timbers. Slightly less than three fourths of the cut of white fir in California and slightly more than one fourth of the cut of white fir in the Inland Empire go into these grades.

The grading rules do not specifically limit defects injurious to the strength. The only specified sizes of defects are those for wane and crook in No. 1 Dimension. The strength of the material in these grades is therefore dependent almost entirely on the grader's judgment of the influence of defects. The material therefore shows a wide range of strength for the judgment of graders will vary considerably. Working stresses cannot be assigned to such grades with any assurance because it is impracticable to determine the strength of the weakest pieces the grade may contain.

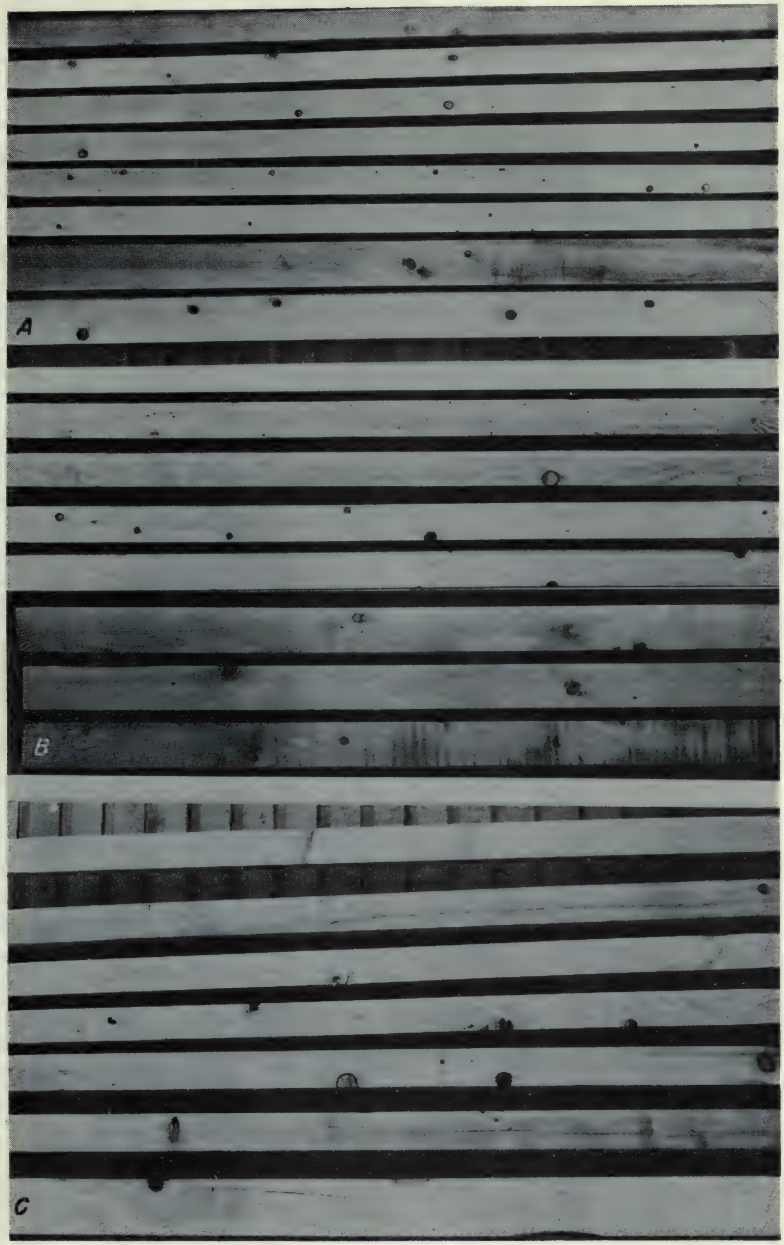
The defects found in the dimension grades in a study made at a California mill are shown in figure 19. The figure shows the percentage of pieces in which each defect occurred irrespective of other defects in the same piece. Of the defects listed, only knots, cross grain, breaks, shake, and checks materially influence strength. The other defects listed have little or no affect on strength, although, as is evident from figure 19, they are a factor in the grade determination. The amount of injury is dependent primarily on size and position of defect, while quality or character has little to do with the strength, although it may adversely affect the appearance. Thus, the injury resulting from a knot depends upon its size and location. Whether it is checked, broken, loose, or even missing, the effect is the same.

SELECT GRADES OF WHITE FIR.

A, C and Better white fir is of high quality containing many boards that would grade B or Better. This 1- by 8-inch finish shows the range in quality in the grade from the clear board on the top to the board on the bottom containing three small knots. B, D Select in white fir is intermediate between the Common and the Select grades having some characteristics of both. The range in quality is shown by the 1- by 6-inch and the 1- by 8-inch finish.

COMMON GRADES IN WHITE FIR.

A, No. 1 Common. White fir produces only a small amount of No. 1 Common. The range in quality of grade is shown by the specimens of 1- by 6-inch shiplap. B, No. 2 Common in white fir is usually sold combined with other grades. It may be sold as No. 2 and Better or No. 3 and Better Common. The range in quality of the No. 2 Common grade is shown by the 1- by 6-inch shiplap. C, No. 3 Common in white fir is sometimes marketed as such but principally as No. 3 Common and Better. The general run of the No. 3 Common grade is shown by the 1- by 6-inch shiplap. D, No. 4 Common 1- by 12-inch white fir boards showing range in quality in the grade.




DIMENSION GRADES IN WHITE FIR.

A, Representative 2- by 4-inch and 2- by 6-inch No. 1 Dimension in white fir. The many small encased knots are typical of the general run of the grade. B, Typical 2- by 4-inch and 2- by 6-inch No. 2 Dimension in white fir. C, Typical 2- by 4-inch and 2- by 6-inch No. 3 Dimenson in white fir. The grade permits defects that reduce strength but do not materially affect stiffness.

WHITE FIR PLANING MILL PRODUCTS.

A, From top to bottom, 1 piece of novelty siding; 2 pieces round edge novelty siding; 2 pieces of tongue and grooved flooring; and 2 pieces of log cabin siding. B, From top to bottom, rustic siding; edge-grain center V ceiling; flat-grain center V ceiling; pulley stile; and back view and face view, respectively, of hollow-back baseboard.

Warping and compression wood are undesirable from a fabrication and use standpoint. Even the checks and splits are ordinarily of small importance to strength because of more serious injury resulting from knots and cross grain.

### EQUIVALENT COMMON-DIMENSION GRADES

Dimension grades are commonly spoken of as being approximately similar to the next lower common grades; that is, No. 1 Dimension is

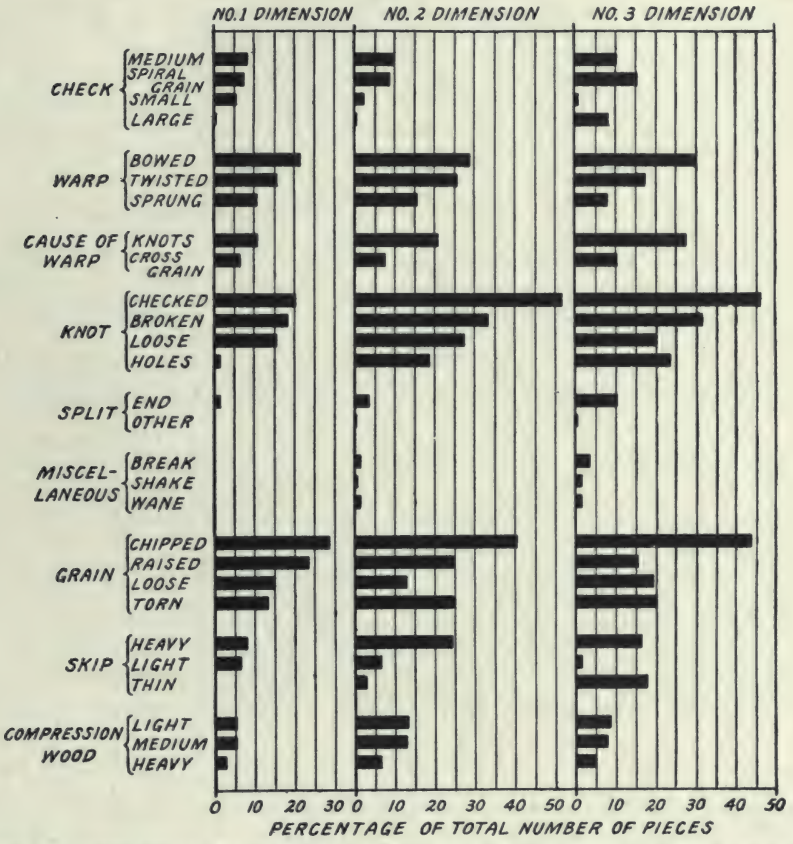



FIGURE 19.—Defects found in 1⁹⁄₁₆- by 4- by 8-inch surfaced and seasoned white fir. Bars show percentage of occurrence of each defect irrespective of other defects in combination in same piece.

similar to No. 2 Common, No. 2 Dimension to No. 3 Common, and No. 3 Dimension to No. 4 Common. As a rough approximation, this is fairly close to the truth, for the major portion of the pieces in any large sample of a given dimension grade will usually fall in the next lower common grade if graded by the common rules. White fir No. 1 Dimension, however, will ordinarily include a substantial proportion of No. 1 Common. In the nominal 2 by 4 inch size there may be as high as 15 to 20 percent of the pieces of No. 1 Dimension that would qualify as D Select or C Select and Better.

The ties produced for the logging railroads are generally of low quality, equivalent to a mixture of about one third each of No. 3,

No. 4, and No. 5 Common if sawed into lumber. Ties occasionally produced for main-line railroads on special order are equivalent to No. 2 Common or Better.

Timbers are of good quality. If sawed into lumber, most of the product would be No. 3 and Better Common, probably equivalent to No. 2 Common in average value.

### NO. 1 DIMENSION

Very little No. 1 Dimension of white fir is shipped. In both California and the Inland Empire it is common practice to combine it with No. 2 Dimension and ship it as No. 2 and Better Dimension (fig. 18). Under more favorable market conditions there will be an increasing tendency to separate No. 1 Dimension. The grade will eventually be considerably more important than is indicated by figure 18.

The grading rules (*30*) define No. 1 Dimension grade thus:

> No 1 Dimension and Timbers must be of a good sound character, but will admit of defects that do not impair the strength of the piece.
>
> On basis of 2 by 4, wane on edge is admissible ½-inch deep, for half the length, or a proportionate amount for a shorter distance on both edges. In any case, one side and two edges should allow a good nailing surface, it being understood, however, that the wane in no case extends over more than one half the side of the piece.
>
> A piece may have a crook of 1 inch (provided it does not occur near an end) in 2 by 4 inches by 16 feet; and ⅛ inch less in each additional 2 inches of width. Pieces longer or shorter than 16 feet may have crook in proportion.
>
> A few wormholes are admissible.

The strength of individual pieces in the grade will vary widely. No. 1 Dimension (pl. 7, *A*), can be used to advantage where the user has wide varying strength requirements and can sort the material in strength classes, or where stiffness rather than bending strength is the controlling factor in design, such as in studding and joists for small-house construction.

Where uniformly high bending strength is required as in timber for mill construction and other structural purposes No. 1 Dimension should be regraded to meet American lumber standards basic provisions for structural material (*28*).

### NO. 2 DIMENSION

Practically all of No. 2 Dimension is sold combined with No. 1 Dimension as No. 2 and Better Dimension. Under the grading rules (*30*) No. 2 Dimension grade—

> will admit of large coarse knots, not necessarily sound, considerable wane, also shake, wormholes, dozey streaks, crooked pieces, or other defects which weaken or impair the pieces to such an extent as to render it unfit for No. 1 Dimension grade. A serious combination of these defects is not admissible in any one piece.

The defects found in the grade are shown in figure 19. The general appearance of the grade is shown in plate 7, *B*. Not only are the defects more numerous than in No. 1 Dimension, as shown by figure 19, but they are larger and more injurious to strength. Dimension of this grade is best adapted to uses where stiffness rather than breaking strength control, such as joists. The decay streaks and unsound knots admissible under the grading rules may reduce bending strength to less than one half that of clear wood but have little influence on stiffness. No. 2 Dimension is not suitable for use in heavy mill construc-

tion or for parts of permanent structure where high strength is desired unless weaker pieces are sorted out by regrading.

#### NO. 3 DIMENSION

A relatively small amount of white fir is sold as No. 3 Dimension. The grading rules (*30*)—

> will admit a great deal of rot and all the imperfections allowed in No. 1 and No. 2 Dimension but in a much more pronounced form.

This is the lowest recognized grade of Dimension and is not recommended for use in permanent structures. It is suitable for temporary construction or crating when rot or other defects which seriously injure the strength are cut out of pieces containing them. The general appearance of the grade is shown in plate 7, *C*. The presence of defects that do not show in the picture is indicated in figure 19.

## WORKING STRESSES

Working stresses are used to determine the safe load-carrying capacity of timbers or the size and number of timbers required to safely carry a given load. They are intended primarily for use in design of structures, but can be used for comparison of structural material of species when grades are comparable. The grades are only comparable when they limit the size, location, and number of defects. Building codes or other engineering specifications generally place a limit on the permissible working stresses.

Safe working stresses cannot be assigned with any degree of assurance to the Dimension and Timber grades described in grading rules (*30*). The absence of specific defect limitation in the Dimension and Timber grades leaves their selection to the judgment of the graders and makes it impossible to determine the strength of a timber acceptable in the grade. It is possible and even probable that some graders may accept timbers in any of the dimension and timber grades that will have less than one half the strength of the clear wood. Working stresses established so that such timbers would safely carry the design load would be so low that they would practically prohibit the use of the grade.

Specifications of the American Society for Testing Materials (*1*) and American Railway Engineering Association (*8*) for grading structural timbers conform to the basic provisions of American lumber standards (*28*). They provide for two grades, Select and Common. Timbers of the Select grade will develop at least 75 percent of the strength of the clear wood, and of the Common grade, 60 percent.

Dimension and timbers graded in accordance with the foregoing specifications will safely take the stresses recommended in table 22 for white fir. The working stresses recommended in the table were obtained by adjusting the strength of the clear wood to meet conditions that exist in service (*17*). Such adjustment is made to take care of the reduction in strength due to the knots and other defects permitted by the grade specifications, the occurrence of pieces below the average strength, the lower strength shown by wood subjected to long-time loads as compared to that shown by test specimens which are loaded only a few minutes, and the weakening effect of certain species characteristics.

TABLE 22.—*Working stresses, in pounds per square inch, for select and common grades of timber conforming to the American lumber standards basic provisions for structural material* [1]

[As recommended by the Forests Products Laboratory]

| Species | Fiber stress in bending [2] | | | | | | | | | | Compression perpendicular to grain | | | Horizontal shear [3] | | Compression parallel to grain (short columns having ratio of length to least dimension of 11 or less) | | | | | | Average modulus of elasticity [4] (not varied with conditions of exposure or with grade) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Continuously dry | | Occasionally wet but quickly dried | | | | More or less continuously damp or wet | | | | Continuously dry | Occasionally wet but quickly dried | More or less continuously damp or wet | Not varied with conditions of exposure | | Continuously dry | | Occasionally wet but quickly dried | | More or less continuously damp or wet | | |
| | All thicknesses | | Material 4 inches and thinner | | Material 5 inches and thicker | | Material 4 inches and thinner | | Material 5 inches and thicker | | | | | | | | | | | | | |
| | Select | Common | Select | Common | Select | Common | Select | Common | Select | Common | Select and Common | | | Select | Common | Select | Common | Select | Common | Select | Common | |
| Ash, black | 1,000 | 800 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 300 | 200 | 150 | 90 | 72 | 650 | 520 | 550 | 440 | 500 | 400 | 1,100,000 |
| Ash, commercial white | 1,400 | 1,120 | 1,070 | 910 | 1,200 | 960 | 890 | 760 | 1,000 | 800 | 500 | 375 | 300 | 125 | 100 | 1,100 | 880 | 1,000 | 800 | 900 | 720 | 1,500,000 |
| Aspen and largetooth aspen | 800 | 640 | 580 | 490 | 650 | 520 | 440 | 370 | 500 | 400 | 150 | 125 | 100 | 80 | 64 | 700 | 560 | 550 | 440 | 450 | 360 | 900,000 |
| Basswood | 800 | 640 | 580 | 490 | 650 | 520 | 440 | 370 | 500 | 400 | 150 | 125 | 100 | 80 | 64 | 700 | 560 | 550 | 440 | 450 | 360 | 900,000 |
| Beech | 1,500 | 1,200 | 1,150 | 980 | 1,300 | 1,040 | 890 | 760 | 1,000 | 800 | 500 | 375 | 300 | 125 | 100 | 1,200 | 960 | 1,100 | 880 | 900 | 720 | 1,600,000 |
| Birch, paper | 900 | 720 | 670 | 570 | 750 | 600 | 530 | 450 | 600 | 480 | 200 | 150 | 100 | 80 | 64 | 650 | 520 | 550 | 440 | 450 | 360 | 1,000,000 |
| Birch, yellow and sweet | 1,500 | 1,200 | 1,150 | 980 | 1,300 | 1,040 | 890 | 760 | 1,000 | 800 | 500 | 375 | 300 | 125 | 100 | 1,200 | 960 | 1,100 | 880 | 900 | 720 | 1,600,000 |
| Cedar, Alaska | 1,100 | 880 | 890 | 760 | 1,000 | 800 | 800 | 680 | 900 | 720 | 250 | 200 | 150 | 90 | 72 | 800 | 640 | 750 | 600 | 650 | 520 | 1,200,000 |
| Cedar, western red | 900 | 720 | 710 | 600 | 800 | 640 | 670 | 570 | 750 | 600 | 200 | 150 | 125 | 80 | 64 | 700 | 560 | 700 | 560 | 650 | 520 | 1,000,000 |
| Cedar, northern and southern white | 750 | 600 | 580 | 490 | 650 | 520 | 530 | 450 | 600 | 480 | 175 | 140 | 100 | 70 | 56 | 550 | 440 | 500 | 400 | 450 | 360 | 800,000 |
| Cedar, Port Orford | 1,100 | 880 | 890 | 760 | 1,000 | 800 | 800 | 680 | 900 | 720 | 250 | 200 | 150 | 90 | 72 | 900 | 720 | 825 | 660 | 750 | 600 | 1,200,000 |
| Chestnut | 950 | 760 | 760 | 650 | 850 | 680 | 620 | 530 | 700 | 560 | 300 | 200 | 150 | 90 | 72 | 800 | 640 | 700 | 560 | 600 | 480 | 1,000,000 |
| Cottonwood, eastern and black | 800 | 640 | 580 | 490 | 650 | 520 | 530 | 450 | 600 | 480 | 150 | 125 | 100 | 80 | 64 | 700 | 560 | 550 | 440 | 450 | 360 | 900,000 |
| Cypress, southern | 1,300 | 1,040 | 980 | 830 | 1,100 | 880 | 800 | 680 | 900 | 720 | 300 | 225 | 200 | 100 | 80 | 1,100 | 880 | 1,000 | 800 | 800 | 640 | 1,200,000 |
| Douglas fir (western Washington and Oregon type) [5] | 1,600 | 1,200 | 1,233 | 983 | 1,387 | 1,040 | 948 | 756 | 1,067 | 800 | [6] 347 | [6] 240 | [6] 213 | 90 | 72 | 1,173 | 880 | 1,067 | 800 | 907 | 680 | 1,600,000 |
| Douglas fir (dense) [5] | 1,750 | 1,400 | 1,349 | 1,147 | 1,517 | 1,213 | 1,037 | 882 | 1,167 | 933 | 379 | 262 | 233 | 105 | 84 | 1,283 | 1,027 | 1,167 | 933 | 992 | 793 | 1,600,000 |
| Douglas fir (Rocky Mountain type) | 1,100 | 880 | 800 | 680 | 900 | 720 | 620 | 530 | 700 | 560 | 275 | 225 | 200 | 85 | 68 | 800 | 640 | 800 | 640 | 700 | 560 | 1,200,000 |
| Elm, rock | 1,500 | 1,200 | 1,150 | 980 | 1,300 | 1,040 | 890 | 760 | 1,000 | 800 | 500 | 375 | 300 | 125 | 100 | 1,200 | 960 | 1,100 | 880 | 900 | 720 | 1,300,000 |
| Elm, slippery and American | 1,100 | 880 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 250 | 175 | 125 | 100 | 80 | 800 | 640 | 750 | 600 | 650 | 520 | 1,200,000 |
| Fir, balsam | 900 | 720 | 670 | 570 | 750 | 600 | 530 | 450 | 600 | 480 | 150 | 125 | 100 | 70 | 56 | 700 | 560 | 600 | 480 | 500 | 400 | 1,000,000 |
| Fir, commercial white | 1,100 | 880 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 300 | 225 | 200 | 70 | 56 | 700 | 560 | 700 | 560 | 600 | 480 | 1,100,000 |
| Gum, red, black, and tupelo | 1,100 | 880 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 300 | 200 | 150 | 100 | 80 | 800 | 640 | 750 | 600 | 650 | 520 | 1,200,000 |
| Hemlock, eastern | 1,100 | 880 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 300 | 225 | 200 | 70 | 56 | 700 | 560 | 700 | 560 | 600 | 480 | 1,100,000 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hemlock, western | 1,300 | 1,040 | 980 | 830 | 1,100 | 880 | 800 | 680 | 900 | 720 | 300 | 225 | 200 | 75 | 60 | 900 | 720 | 900 | 720 | 800 | 640 | 1,400,000 |
| Hickory (true and pecan) | 1,900 | 1,520 | 1,330 | 1,130 | 1,500 | 1,200 | 1,070 | 910 | 1,200 | 960 | 600 | 400 | 350 | 140 | 112 | 1,500 | 1,200 | 1,200 | 960 | 1,000 | 800 | 1,800,000 |
| Larch, western | 1,200 | 960 | 980 | 830 | 1,100 | 880 | 800 | 680 | 900 | 720 | 325 | 225 | 200 | 100 | 80 | 1,100 | 880 | 1,000 | 800 | 800 | 640 | 1,300,000 |
| Maple, sugar and black | 1,500 | 1,200 | 1,150 | 980 | 1,300 | 1,040 | 890 | 760 | 1,000 | 800 | 500 | 375 | 300 | 125 | 100 | 1,200 | 960 | 1,100 | 880 | 900 | 720 | 1,600,000 |
| Maple, red and silver | 1,000 | 800 | 800 | 680 | 900 | 720 | 620 | 530 | 700 | 560 | 350 | 250 | 200 | 100 | 80 | 800 | 640 | 700 | 560 | 600 | 480 | 1,100,000 |
| Oak, commercial red and white | 1,400 | 1,120 | 1,070 | 910 | 1,200 | 960 | 890 | 760 | 1,000 | 800 | 500 | 375 | 300 | 125 | 100 | 1,000 | 800 | 900 | 720 | 800 | 640 | 1,500,000 |
| Pine, southern yellow [5] | ------ | 1,200 | ------ | 983 | ------ | 1,040 | ------ | 756 | ------ | 800 | (6) | (6) | (6) | ------ | 88 | ------ | 880 | ------ | 800 | ------ | 680 | 1,600,000 |
| Pine, southern yellow (dense) [5] | 1,750 | 1,400 | 1,349 | 1,147 | 1,517 | 1,213 | 1,037 | 882 | 1,167 | 933 | 379 | 262 | 233 | 128 | 103 | 1,283 | 1,027 | 1,167 | 933 | 992 | 793 | 1,600,000 |
| Pine, northern white, western white, ponderosa, and sugar | 900 | 720 | 710 | 600 | 800 | 640 | 670 | 570 | 750 | 600 | 250 | 150 | 125 | 85 | 68 | 750 | 600 | 750 | 600 | 650 | 520 | 1,000,000 |
| Pine, Norway | 1,100 | 880 | 890 | 760 | 1,000 | 800 | 710 | 600 | 800 | 640 | 300 | 175 | 150 | 85 | 68 | 800 | 640 | 800 | 640 | 700 | 560 | 1,200,000 |
| Poplar, yellow | 1,000 | 800 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 250 | 150 | 125 | 80 | 64 | 800 | 640 | 700 | 560 | 600 | 480 | 1,100,000 |
| Redwood | 1,200 | 960 | 890 | 760 | 1,000 | 800 | 710 | 600 | 800 | 640 | 250 | 150 | 125 | 70 | 56 | 1,000 | 800 | 900 | 720 | 750 | 600 | 1,200,000 |
| Spruce, red, white, and Sitka | 1,100 | 880 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 250 | 150 | 125 | 85 | 68 | 800 | 640 | 750 | 600 | 650 | 520 | 1,200,000 |
| Spruce, Engelmann | 750 | 600 | 580 | 490 | 650 | 520 | 440 | 370 | 500 | 400 | 175 | 140 | 100 | 70 | 56 | 600 | 480 | 550 | 440 | 450 | 360 | 800,000 |
| Sycamore | 1,100 | 880 | 800 | 680 | 900 | 720 | 710 | 600 | 800 | 640 | 300 | 200 | 150 | 80 | 64 | 800 | 640 | 750 | 600 | 650 | 520 | 1,200,000 |
| Tamarack (eastern) | 1,200 | 960 | 980 | 830 | 1,100 | 880 | 800 | 680 | 900 | 720 | 300 | 225 | 200 | 95 | 76 | 1,000 | 800 | 900 | 720 | 800 | 640 | 1,300,000 |

[1] American lumber standards: Basic provisions for American lumber standards grades are published in U.S. Department of Commerce Simplified Practice Recommendation R16–29 (*28*); specifications for grades conforming to American lumber standards are published in the 1927 standards of the American Society for Testing Materials (*1*), and in American Railway Engineering Association Bulletin (*8*).

[2] Stress in tension: The working stresses recommended for fiber stress in bending may be safely used for tension parallel to grain.

[3] Joint details: The shearing stresses for joint details may be taken for any grades as 50 percent greater than the horizontal shear values for the select grade.

[4] Factors to be applied to average modulus of elasticity values: The values for modulus of elasticity are average for species and not safe working stresses. They may be used as given for computing average deflection of beams. When it is desired to prevent sag in beams values one half those given should be used. In figuring safe loads for long columns values one third those given should be used.

[5] Exact figures given: In order to preserve the exact numerical relations among working stresses for grades involving rate of growth and density requirements the values for Douglas fir (western Washington and Oregon type) and for southern yellow pine have not been rounded off, as have the values for the other species.

[6] Working stresses for the Common grade: The values given are for the Select grade. Working stresses in compression perpendicular to grain for the common grades of Douglas fir (western Washington and Oregon type) and southern yellow pine are 325, 225, and 200, respectively, for continuously dry, occasionally wet but quickly dried, and more or less continuously damp or wet conditions.

In addition the working stresses of table 22 provide a factor of safety [11] to take care of small accidental overloads. In a structure designed from the stresses recommended in table 22 occasional timbers may be expected to fail in bending immediately upon being subjected to twice their design loads and about one timber in a hundred will fail at one and one half times the design load if the load remains on the structure for several years.

The adjustment for the injurious effect of defects of necessity limits the application of working stresses to specific grades, except that the recommended working stress for end compression perpendicular to the grain and the average values of modulus of elasticity are applicable to all grades, since these two properties are not seriously affected by defects.

The application of working stresses to dimension or timbers graded under 1929 grading rules (*30*) requires regrading. Such a regrading is not difficult to accomplish with the aid of structural grade examples (*1*, *8*, *28*).

## USES OF WHITE FIR

White fir (p. 2) goes into a comparatively small number of uses. About three fourths of the cut is used for construction purposes. Of the remaining one fourth all but a fraction of 1 percent goes into boxes and crates, planing-mill products, sash, doors, blinds, and general millwork. Less than 0.5 percent goes into industrial uses.

The principal uses of western true firs [12] are shown in figure 20. The figure compares the use of western true firs with the average of 14 of the principal commercial softwoods based on the percentage of the cut going into the various uses. The use classifications are very broad, and each includes a number of more specific individual uses. Thus, under planing-mill products are grouped 20 or more specific uses, such as flooring, ceiling, partition, and the like. Generally the comparison shows that a higher percentage of the cut of the western true firs is used for building and containers and a smaller percentage for planing-mill products, general millwork, and industrial uses than of the cut of the average softwood. The small percentage of material of the select grades cut from white fir is partly the cause for the use distribution shown. Figure 20 does not show how successful the white firs are in meeting the requirements of the various uses. Service records over a long period are the best criterion of the suitability of a wood for a use. In the absence of such records the suitability can best be determined by comparing the properties of wood with the requirements of the use. Use requirements, however, are not always known and even when known are subject to change with time and conditions. Determination of the suitability of a wood for a use from analysis of properties should be checked against the experience of users if possible. In the following discussion of the uses of white fir, therefore, there is presented a comparison of the properties of the wood and use requirements insofar as they are known. Price is not considered, for it varies too widely with time and place. The discussion of uses of white fir can, therefore, be

[11] UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE. SIGNIFICANCE OF THE "FACTOR OF SAFETY" IN WORKING STRESSES FOR STRUCTURAL TIMBER. U.S.Dept.Agr., Forest Serv. Forest Prod. Lab. Tech. Note 222, 3 p. [n.d.] [Mimeographed.]

[12] UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE. LUMBER USED IN MANUFACTURE, PRELIMINARY STATISTICS, FOREST SURVEY OF THE UNITED STATES. U.S.Dept.Agr., Forest Serv. 55 p. 1928. [Mimeographed.]

considered only as an aid to the consumer in determining if white fir is the most economical wood for his purpose. He must evaluate difference in properties or service and weigh them against difference in price of competitive species.

### WHITE FIR BOXES AND CRATES

Boxes and crates are from a quantitative standpoint the most important of the industrial uses of white fir. About one sixth of the annual lumber cut of western true firs or about 46,000,000 board feet, go into this use. The western true firs rank seventh among the softwoods in amount of lumber used for containers. They owe their popularity as container woods to their clean bright appearance and white color, their light weight, freedom from stain and pitch defects, lack of odor when dry, ease of working, availability, and low cost. Their bending strength, stiffness, and shock-resisting ability are about the same as those of the soft pines, which are our principal

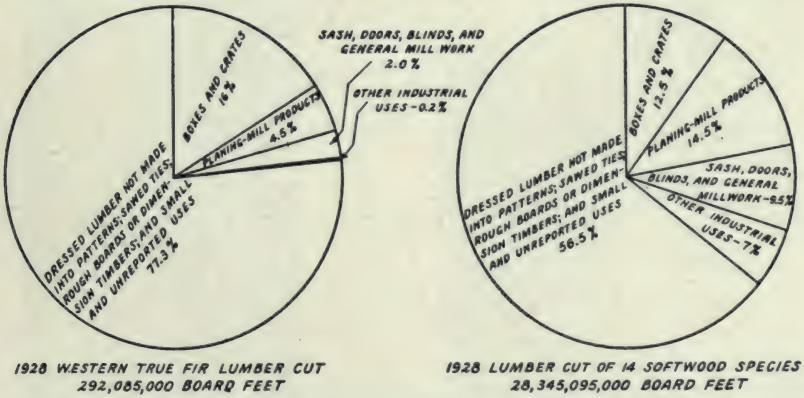

DRESSED LUMBER NOT MADE INTO PATTERNS; SAWED TIES; ROUGH BOARDS OR DIMENSION TIMBERS; AND SMALL AND UNREPORTED USES 77.3%
BOXES AND CRATES 16%
PLANING-MILL PRODUCTS 4.5%
SASH, DOORS, BLINDS, AND GENERAL MILL WORK 2.0%
OTHER INDUSTRIAL USES-0.2%
1928 WESTERN TRUE FIR LUMBER CUT 292,085,000 BOARD FEET
DRESSED LUMBER NOT MADE INTO PATTERNS; SAWED TIES; ROUGH BOARDS OR DIMENSION TIMBERS; AND SMALL AND UNREPORTED USES 56.5%
BOXES AND CRATES 12.5%
PLANING-MILL PRODUCTS 14.5%
SASH, DOORS, BLINDS, AND GENERAL MILLWORK-9.5%
OTHER INDUSTRIAL USES-7%
1928 LUMBER CUT OF 14 SOFTWOOD SPECIES 28,345,095,000 BOARD FEET

FIGURE 20.—The use of western true firs compared with that of other softwoods. A high percentage of the lumber cut of true firs is used in general construction, more than the average is used for boxes and crates.

container woods. The soft pines, however, have a more uniform texture, split less in nailing, and have a higher nail-holding power.

### BOXES

White fir is grouped for box making with ponderosa pine, western white pine, northern white pine, sugar pine, and the other softer and lighter woods (*19*). The groupings are made in accordance with the nail-holding power and other properties of the wood (*19*). There are four groups and white fir is in the most favorable group 1. The woods in this group are relatively free from splitting in nailing, have moderate nail-holding power, moderate strength as a beam, and moderate shock-resisting ability. Boxes made of the woods within a group, however, are not necessarily equally serviceable.

A detailed study (*5*) was made by the Forest Products Laboratory to determine the suitability of several species, including white fir (*Abies concolor*) and lowland white fir, for manufacture of containers. The tests, as well as past experience in box design, indicate that standard canned-food boxes of white fir could be built into considerably better boxes by using smaller nails spaced closer than the stand-

ard of seven sixpenny nails to a nailing edge. Smaller nails will reduce splitting and more nails will increase holding power. The primary cause of failure when the boxes were tested to destruction was splitting of ends by the nails, nails pulling from end grain, and splitting of sides, tops, and bottoms at the nails.

The test demonstrated conclusively that good service cannot be expected from boxes built from green or wet lumber of any species. The boxes of white fir (*Abies concolor*) and lowland white fir made of green or wet lumber lost about three fourths of their resistance to rough handling when dried to about 10-percent moisture content in storage. On the other hand, nails in boxes made of lumber between

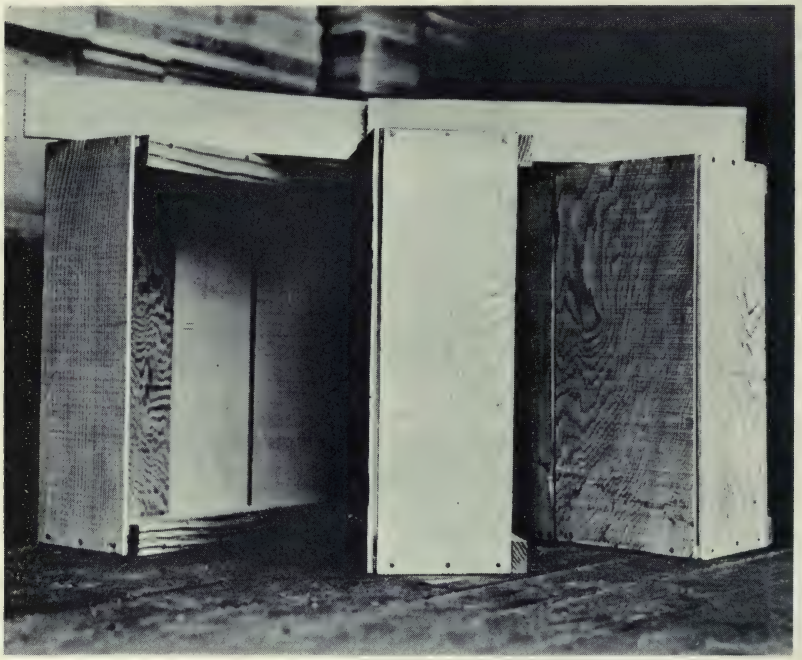


FIGURE 21.—High-quality white-fir boxes used for grape lugs.

12- and 15-percent moisture content did not pull when the boxes were tested to failure. The white fir (*A. concolor*) boxes withstood about the same rough handling as ponderosa pine boxes when both were made from lumber at about 15-percent moisture content.

A list of different kinds of boxes for which white fir is used would include practically every ordinary type of box made. White fir has, however, been most widely used in the manufacture of containers for foodstuffs (figs. 21 and 22).

A series of tests on white fir (*Abies concolor*) boxes was made to determine the possibilities of improving nail-holding power and of reducing splitting. The type of box, size of nail, and nail spacing were the same as those used in the previously mentioned tests. Three groups of 5 boxes each were tested. Each group had 3 boxes nailed with blunted nails, which were tapered and chemically treated (p. 31); the other 2 boxes in each group were nailed with cement-coated nails. All boxes were made from air-dry lumber at about

13-percent moisture content. One group of boxes was nailed and tested immediately, another was stored under damp conditions for 53 days and tested at a moisture content of about 23 percent. The other was stored under dry conditions the same length of time and tested at about 6-percent moisture. The conditioning of the boxes was intended to reproduce as nearly as practicable conditions of service—where boxes are nailed, packed, and shipped without storage to local or nearby regions; where they are placed in cold storage or shipped in refrigerator cars; and where they are stored in heated buildings or used under hot, dry conditions such as exist in some fields, orchards, and vineyards.

In general, the test results conform to the conclusions drawn from previous tests that white fir makes an excellent box. The boxes showed little tendency to split in nailing. Both the special blunted, chemically treated nails and the cement-coated nails held well and few failures resulted from nails pulling. The blunting of the nails increased the tendency of the wood to shear at the nails. The chemical treatment of nails increased nail-holding power sufficient to more than offset the loss of nail-holding power caused by blunting, except in boxes stored at 13-percent moisture and dried to 6-percent moisture. The amount of rough handling withstood by boxes of all three groups, and types of failure, indicated that they would give satisfactory service.

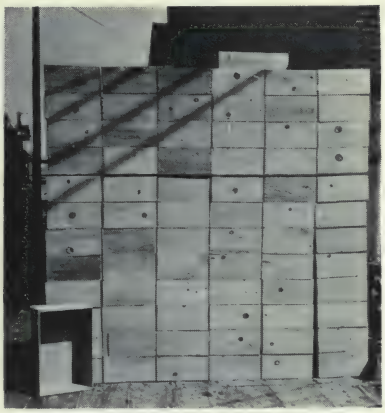


FIGURE 22.—Low-priced white-fir boxes used for the shipment of shooks for food boxes.

The tests indicate that it is not necessary to use a special nail to make a satisfactory box of white fir. If the lumber is properly seasoned and the proper size and number of nails are used (*19*), the ordinary cement-coated nail is satisfactory.

### CRATES

Well-seasoned white fir is well adapted to all types of crates. It is equally adapted to crates for small-sized or light articles and for large, bulky, and heavy articles. Crates for odd-shaped articles, which require more cutting and hand fitting than the ordinary crate, can be made economically from white fir because of its easy working qualities. Its light weight adapts it to crating for all articles of light weight because the shipping charges on such articles depend largely on the weight of the crate.

White fir is especially adapted for melon and vegetable crates because of its lack of odor and resin and its light weight. Large quantities are used in California for shipment of melons, sweetpotatoes, lettuce, and celery. For these particular commodities white fir on its merits has successfully broken through the long-standing barrier of traditionally popular competitive species. Its popularity as a container for such commodities will increase as increasing use by the growers demonstrates its suitability.

### PLANING-MILL PRODUCTS

About 4 percent of the lumber cut of western true firs (p. 2) goes into planing-mill products. This is only one third of the percentage of the average softwood used for this purpose. The small amount of white fir going into planing-mill products is due to the small percentage of the select grades obtained from white fir.

Planing-mill products include a wide variety of items. They are used for interior and exterior trim, flooring, roofing, and framing. The property requirements for all items of interior trim are practically identical. The requirements for many items of exterior trim are also identical. The items going into these uses can therefore be discussed in groups.

Practically all items of interior and exterior trim are manufactured from white fir. Table 23 lists the sizes and grades of the standard items that are available.

TABLE 23.—*Principal planing-mill products of white fir*

| Product | Thicknesses, inches | Widths, inches | Grades |
|---|---|---|---|
| Finish, surfaced 2 sides or surfaced 4 sides. | 1 1/16 to 2 | 4 to 12 | C and Better, D Select. |
| Baseboard | (1) | (1) | Do. |
| Casings | (1) | (1) | Do. |
| Frame material | (1) | (1) | Do. |
| Miscellaneous moldings | (1) | (1) | Do. |
| Battens | (1) | (1) | Do. |
| Bevel siding | 9/16 x 7/16 | 4, 5, 6 | Do. |
| Rustic siding | (1) | (1) | Do. |
| Drop siding | 9/16, 1 1/16, 1, 1 1/4 | 3, 4, 5, 6, 8 | No. 2 Common or Better. |
| Flooring | 9/16, 1 1/16, 1, 1 1/4 | 3, 4, 5, 6, 8 | No. 3 Common or Better. |
| Partition | 9/16, 1 1/16, 1, 1 1/4 | 3, 4, 5, 6, 8 | Do. |
| Ceiling | (1) | (1) | Do. |
| Dressed and matched | 1 1/16, 1, 1 1/4, 1 1/2, 2 | 4 to 12 | All grades. |
| Shiplap | 1 1/16, 1, 2 | 4 to 12 | Do. |
| Grooved roofing | 1 to 2 | 4 to 10 | No. 3 Common or Better. |
| Do | Greater than 2 inches | 4 to 10 | No. 2 Common or Better. |

[1] All standard patterns and sizes.

Local demand has resulted in the regular stocking by some retail yards of various special patterns in white fir, such as hollow-back baseboards, round-edge casing, two-lap drop siding, V-grooved ceiling, grooved roofing, partition, stops, hook strip, and quarter-round and half-round moldings. Some of these items are shown in plate 8.

Almost any yard regularly handling white fir carries surfaced 4 sides or surfaced 2 sides C and Better trim, common shiplap, and 2 or 3 grades and sizes of dressed and matched stock in addition to common boards and dimension.

Practically any pattern made in pine may be obtained in white fir from the larger operators, who ordinarily carry most of their white fir in the rough until orders are received. The range of stock carried in white fir is confined mostly to thicknesses of 2 inches and under and widths from 3 to 12 inches. Thicker and wider material is produced, but usually on special order.

### INTERIOR TRIM

The requirements for all items of interior trim are practically identical. Finish, baseboard, casing, partition, and ceiling all must stay in place and take and hold enamel or natural finishes. Resistance to marring and denting are also desirable. Interior trim, however, is chosen primarily for appearance.

The white firs can be used for either enamel or natural finishes. The figure, while pronounced enough to give a pleasing effect with natural finishes, especially when accentuated by staining, is not sufficiently pronounced to make it hard to cover with enamel. No trouble will be experienced from grain raising, which is objectionable with either enamel or natural finish, provided the wood is thoroughly dry when dressed and put in place, and all boards are turned bark side out. Dressed wet there is not only a tendency for grain to rise, but the wood fuzzes making it difficult to obtain the desired smoothness of finish. Figure 23 and plate 9 show white fir used for interior trim. White fir is a stable wood and will stay in place well if dry when installed because the shrinkage is small, especially in edge-grained material. Moreover, straight-grained white fir has little tendency to warp. The wood of the white fir, however, is soft and is consequently readily marred or dented. In this respect white fir is similar to ponderosa pine and inferior to the hemlocks and hard pines.

#### EXTERIOR TRIM

Siding is the principal item of exterior trim made from white fir. Bevel, rustic, and drop siding are the three principal patterns. Some white-fir finish is used for trim.

The most important property requirements for exterior trim are stability, ability to take and hold paint, and ease of fabrication. Dry white fir is a stable wood, it has small shrinkage and little tendency to warp. The wood weathers rather rapidly. If left unprotected by paint, large open cracks will develop. A good three-coat paint job applied soon after construction and then maintained will practically eliminate weathering (p. 32). Repainting should not be postponed until bare wood is exposed, but should occur when a close examination reveals fine cracks in the paint coat. White fir holds paint well. Its ability to hold paint is a very desirable asset in exterior trim. The ease with which white fir is cut, sawed, and fitted makes it popular with builders. In this respect white-fir trim is very similar to trim of the spruces and hemlocks.

#### FLOORING

Unless it has received a preservative treatment white fir (p. 32) is unsuited for flooring used where the decay hazard is high, such as in exposed porches. Little white fir is used for finished floors in small houses. The wood mars and dents more readily than Douglas fir or western larch, and the small percentage of the material in the select grades limits the amount suitable for such floors. In recent years, however, some of the lighter weight, light-colored, softer conifers have been successfully used for fine finished flooring, notably western hemlock. Judged by its properties edge-grained white fir could be used where the wear is not heavy, such as in the second floor of a dwelling. Service records are not available to confirm this conclusion and until a few trial installations are made the wood cannot be recommended for such floors.

White fir flooring is used principally in rough floors. Most of it is of No. 2 Common or Better grade. The knots and other defects present in the grade, while objectionable in floors with natural finish, are acceptable in some painted floors, such as in cottages and protected porches.

Recent observations indicate that woods as soft as white fir can be used where mechanical wear is heavy. But where there is a moderate decay hazard, mechanical wear rather than decay is often

FIGURE 23.—White fir cabinet and cupboard finished in white enamel. The color of wood and character of figure make a good base for enamel finish.

responsible for replacement of white fir. The softer woods mash or crush and do not wear down so rapidly as harder softwoods that sliver and splinter. There is some evidence that white fir will give equal or better service than heavier and harder softwoods under heavy mechanical wear, but additional service records are necessary before it

can be unqualifiedly recommended. It cannot be recommended as an alternate for the tougher hardwoods such as oak or black gum. Figure 24 shows heavy white fir flooring for mill construction.

### SASH, DOOR, BLINDS, AND GENERAL MILLWORK

About 2 percent or 6,000,000 board feet of the western true firs go into sash, door, blinds, and general millwork. The statistical data do not indicate how much of this is obtained from white fir.

#### SASH, DOOR, BLINDS

Sash and door production from white fir is handicapped by the fact that most white fir producers have enough of the soft pines to

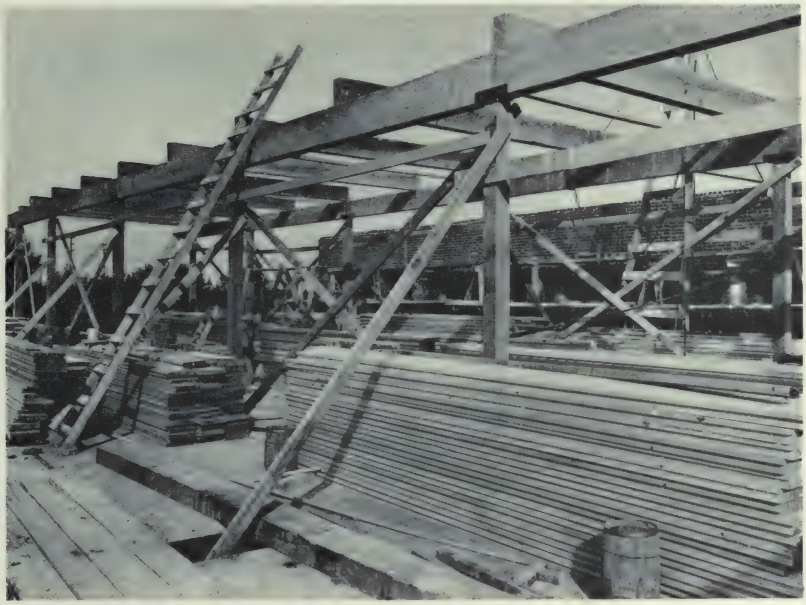


FIGURE 24.—Piles of heavy, tongue-and-groove white fir flooring awaiting installation in a factory.

fill all their orders. There is therefore little incentive for developing a market for white fir doors or millwork. White fir has the stability, painting, and finishing characteristics necessary for sash, doors, and blinds. White fir is equally suitable insofar as decay resistance is concerned as any woods used for this purpose in which unlimited amounts of sapwood are permitted. White fir is not so easy to work as the soft pines but is better adapted to natural finishes where a figured grain is desired. The tendency of white fir to check when exposed unpainted requires that all exposed white fir millwork be protected by paint or a natural finish (p. 39).

#### CORE STOCK

White fir makes a good core stock for veneer doors. The wood is easily glued under a wide range of gluing conditions, and it is stable when dry, having small shrinkage and little tendency to warp. Common lumber and tongue-and-groove stock are used for core stock.

### FIRE DOORS

The properties of white fire are very similar to those of some of the species now listed as acceptable for tin-covered fire doors (*16*). White fir meets the requirements for low resin content as well or better than any species now in the acceptable list. Of the acceptable species only the cedars and western white pine, northern white pine, and sugar pine are lighter in weight. The nail-holding power of white fir is low. It is, however, higher than that of one acceptable species and is sufficient to hold three-ply cores together, especially as specifications (*16*) require through nailing and clinching of nails. If wood is dried to below 15-percent moisture content when metal covering is applied, the decay hazard becomes so low that species with low decay resistance can be used. The present specifications call for No. 1 Common or better. A select grade or specifically selected white fir would be required to meet the specifications because No. 1 Common is seldom segregated. Before a market for white fir can be developed with the manufacturers of fire doors, the wood must receive the approval of the National Board of Fire Underwriters.

### GENERAL MILLWORK

The production of items of general millwork other than those just discussed is small and relatively unimportant. Bathroom cabinets, kitchen cabinets, cupboards, and other built-in products are made entirely of white fir or white fir mixed with one of the soft pines, principally ponderosa pine. Some window frames and pulley stiles are made but they are not readily available to consumers. Generally white fir makes excellent millwork but is handicapped by always being produced along with the more popular species for general millwork.

### WHITE FIR FOR SMALL-HOUSE CONSTRUCTION

More white fir (p. 2) is used in the construction of small houses than for all other purposes. About three fourths of all commercial white fir lumber cut annually, or about one fourth of a billion board feet, goes into small-house construction. The percentage of white fir used for this purpose is larger than that of the average for the softwoods.

The species is used largely in the form of dimension and common boards. It is, therefore, used most in frames, subfloors, and sheathing. There are, however, houses in California built of white fir from cellar to attic, the only other wood used being in foundation sills and shingles.

Considerable difference of opinion exists concerning the merits of white fir for construction purposes. In some localities, the wood has established a desirable reputation as a construction material. In other localities, the wood is regarded as inferior for house construction. Where the wood has given satisfaction it has been dry and usually standard or oversized. Where dissatisfaction has been encountered, the wood usually has been found to be insufficiently seasoned. Other important contributing causes have been substandard sizes, poor grading, improper use because of lack of knowledge of properties and peculiarities of species, and poor or inefficient workmanship. Taken as a whole the complaints are not primarily an indictment of the wood, but show the necessity of improved seasoning, grading, handling,

and a better knowledge of the properties. The complaints caused by inherent characteristics of the wood are minor, and their cause is known and a remedy is available. Thus, where the nail-holding power is inadequate it can be increased by the use of more nails or by the use of chemically treated nails with high holding power (p. 30). Splitting can be reduced by the use of blunt, tapered nails. Substandard sizes are largely responsible for inadequate strength or stiffness. A comparison of the properties of white fir with those of eastern spruce and eastern hemlock, two woods that are successfully used in house construction, indicates that white fir may be used for the same purpose.

The properties desired in building material may be divided into two groups—one containing those properties that tend to insure satisfactory service when the wood is in place, the other containing those properties that tend to facilitate construction and thus reduce costs. Strength, stiffness, nail-holding power, and stability are important properties in the first group. Light weight, softness, and ease of working are those of the second. A species cannot excel in the properties of both groups, since, for instance, if it has high strength it is comparatively heavy and hard.

The adequacy of the strength of white fir for structural purposes is shown by recommended working stresses (table 22). The working stresses recommended for white fir compare favorably with those of a number of species that have been successfully used in the construction of small houses. They are the same throughout as those for eastern hemlock, a wood used extensively in the Lake States in house construction. The working stresses of eastern spruce, which has for years been a standard construction material in New England, do not differ greatly from those for white fir. The working stresses for all of these woods are lower than those for Douglas fir (coast type) and southern yellow pine. The lower working stresses of white fir do not mean that the wood is unsuited for structural work but indicate the necessity for larger sizes to obtain strength and stiffness equal to that obtained with stronger woods. For example, a 2- by 8-inch white fir rafter is stronger and stiffer than a 2- by 6-inch rafter of a comparable grade of any species in table 22. It is evident, therefore, that adequate strength or stiffness may be obtained by proper design as well as by species selection.

The size of some items, such as studding, are largely fixed by common practice. American lumber standards sizes were established with a view to having the sizes adequate for the lighter weight, weaker species. White fir can in many items, therefore, be used in the same sizes as the heavier and stronger species. The value of the greater strength and stiffness of houses constructed of the heavier and stronger woods is difficult to evaluate. While oversized or extra standard sizes of white fir are not necessary to meet the requirements of houses constructed in accordance with accepted standards of good practice, substandard sizes, especially in the lighter weight and weaker species, such as white fir, are questionable.

### FRAMING

Probably the largest single use of white fir is for framing for small houses. It is used for all items of framing, including studding, rafters, joists, sills, and plates. Although these uses differ in many respects, they have a number of common requirements, including

nail-holding power, stability, ease of working, and light weight. White fir is light in weight, easy to work, stable, and dimension items have the reputation of being straight and easy to fabricate. Their strength, nail-holding power, and lack of decay resistance as compared with certain other species have been objected to by consumers in some localities. Trouble in these respects, however, may be due to many other factors than the inherent properties of the wood itself.

Bending strength is an important requirement of rafters, but less so of joists and studding. White-fir rafters to be the equal in strength of Douglas fir (coast type) or southern yellow pine of comparable grade should be, other dimensions being equal, about one sixth wider, or the span should be shortened about one third by bracing or otherwise. Thus, Douglas fir when the design calls for a 2- by 6-inch Douglas fir (coast type) rafter to obtain necessary bending strength,

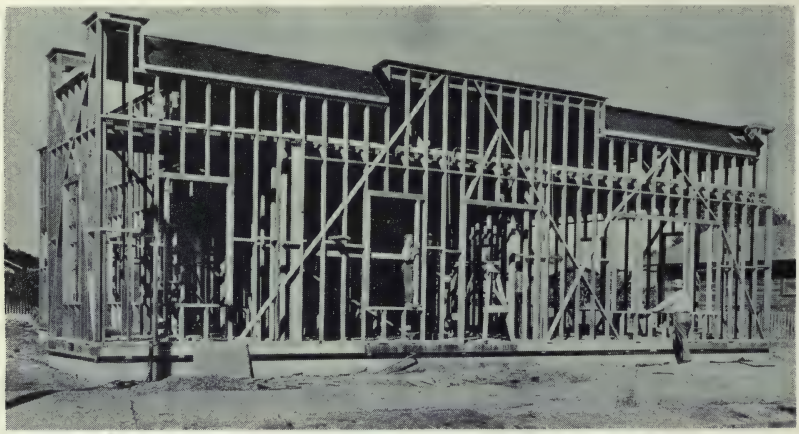


FIGURE 25.—White-fir studding. It is light in weight, straight, and the principal dimension item produced from the species.

a 2- by 7-inch rafter in white fir would be required to give the same strength. Since a 2- by 7-inch rafter is not a standard size, a 2- by 8-inch rafter would probably have to be used, even though it is larger than is required to obtain the necessary strength. The added strength and stiffness resulting from the extra inch has a value, but it is difficult to evaluate. On the other hand where load requirements call for nonstandard 2- by 5-inch Douglas fir (coast type) a standard 2- by 6-inch would probably be used, which is the same size as would be used with white fir.

Stiffness is the principal requirement of joists and studding in small buildings (fig. 25). The size required to obtain the desired stiffness is much larger than is necessary to carry any loads to which joists or studs are likely to be subjected. Joists and studs in small houses, therefore, seldom if ever break. Grade likewise is not very important in joists and studs, for knots, knot holes, and other defects have little influence on stiffness. White-fir joists to have the same stiffness as those of Douglas fir (coast type) or southern yellow pine should be one eighth deeper or the span would have to be about one eighth shorter. Thus, a 2- by 8-inch joist in Douglas fir (coast type), any grade, has about the same stiffness as 2- by 9-inch white-

fir joist of any grade, other things being equal; or a white-fir joist on a 16-foot span has the same stiffness as one of Douglas fir (coast type) on a 14-foot span, other dimensions being the same. A white fir substandard joist is 1$\frac{9}{16}$ inches thick and is 4 per cent lower in stiffness and breaking strength than a standard 1$\frac{5}{8}$-inch thick joist of same depth, which is not an especially significant difference. On the other hand, a white-fir substandard 2- by 4-inch piece is about 12 percent lower in stiffness than one of standard size. It is difficult to determine what this difference in stiffness of joists and studs would mean in terms of service. In the lighter weight, weaker softwoods, the

FIGURE 26.—White-fir sheathing and framing. Much of the species is used in light construction of this type in California.

use of the weaker, substandard sizes is questionable and cannot be recommended for first-class construction.

White-fir framing has acquired its best reputation where oversized 1$\frac{3}{4}$- or 1$\frac{7}{8}$-inch thick dimension, principally 1$\frac{7}{8}$ inch, is used. This dimension is sold as "Valley dimension" by most of the mills in the Sierras of California. The 1$\frac{7}{8}$-inch stock is 15 percent higher than the standard 1$\frac{5}{8}$-inch stock in bending strength and stiffness when used on edge. When used flatwise or as studding it is about 50 percent higher in stiffness than stock of standard thickness.

Extra standard sizes in white fir are not ordinarily required for satisfactory service. Experience indicates that American lumber standard sizes will give satisfactory service. Standard-sized white fir is obtainable, but the common practice is to ship substandard size. The consumer should, therefore, specify standard size for framing material.

Experience with white-fir framing (fig. 26) throughout the country indicates that its nail-holding power is satisfactory. It will hold

sheathing, siding, or other covering provided the framing is dry when covering is put in place. When and where more nail holding is required than is obtained with standard methods of nailing on covering, it is readily obtainable with white fir by the use of more nails or by the use of chemically treated nails (p. 31).

Decay resistance is not a requirement in most framing items. Sills in contact with the ground or which may be subjected to moist or wet conditions have a high decay hazard, and white fir is unsuited for such use unless treated with a preservative. On the other hand, most framing, once it is dry, remains dry. Under such conditions white-fir framing will last indefinitely.

### SUBFLOORS AND SHEATHING

A little less than one fourth of the white-fir lumber produced in California and over one half of that produced in the Inland Empire is marketed as common boards and shiplap. These two items are used extensively for subfloors and sheathing in small houses.

Stiffness, insulation, and ease of working are the principal requirements for subfloors, and insulation and ease of working for sheathing. The denser species have the greater stiffness and the lighter-weight species are easier to work and have greater insulating value.

High nail-holding power is not considered an essential requirement, since the nail-holding power of framing should be relied upon to hold finish flooring and siding in place. The species characteristics usually given most consideration by builder and contractor are those which facilitate construction.

The characteristic defects in comparable grades of different species are also given some consideration in subfloors and sheathing. Small tight knots, even though numerous, are preferred to large or loose ones. The knots in white fir in the grades generally used for sheathing and subfloors are intermediate in size and number, but many of them may be loose, checked, or broken. This unfavorable characteristic of the knots as well as the lower strength and stiffness of white fir must be weighted against the favorable combination of light weight and ease of working and handling. What to use depends upon whether a tight grade is more important from a service standpoint than any difference in strength or stiffness.

Price and degree of seasoning, however, rather than the properties and characteristics, usually determine the choice of species for subflooring and sheathing. In large cities a difference as small as 25 cents per thousand board feet is usually sufficient to offset species differences with contractors and retail lumber dealers. In small towns, especially in farming sections, species differences are given more consideration, but even here $1 per thousand board feet difference in price is usually sufficient to overcome species preferences. The importance of well-seasoned sheathing and subflooring in obtaining a tight house or floor, while often ignored in the past, is rapidly being recognized by builders. Any species must be marketed dry if it is to hold its own as wood for subfloors and sheathing.

### HEAVY CONSTRUCTION

Very little white fir is used for heavy structural work. Structural timbers are usually chosen for strength, that being the most important requirement. The greater strength of heavier and harder species

usually outweighs the advantages the white firs have as a result of their light weight and ease of working. In or near regions of growth, however, a favorable combination of conditions has resulted in some use of white fir (fig. 27). Such favorable combinations of circumstances, however, are confined to places where the principal species associated in the forest with white fir are soft, lightweight woods of no greater strength.

White fir structural timbers go into two principal types of use—temporary bridges and trestles and mill construction. Logging railroads are the principal users of untreated white-fir timbers in bridges and trestles (fig. 28). The life required of timbers in logging railroads is usually short and white fir may be used successfully untreated. Treated white-fir timbers could be used in more permanent bridges

FIGURE 27.—White fir used for concrete forms and heavy mill construction.

and trestles. Little, however, is used for this purpose, for preservative treated white-fir timbers are not at present readily available and little effort has been made to develop this market. In mill construction white fir is used for posts, joists, girders, heavy flooring, and roofing. The number of installations is comparatively small. Two installations, 1 in a bakery (fig. 29) and 1 in a laundry (fig. 30), are known to have proved successful. Both of these types of occupancy subject timbers to exceptionally severe conditions. The condition of timbers and planks after 5 to 7 years' service indicates that checking and twisting are less than would be expected with a heavier and stronger species.

## INDUSTRIAL USES

### RAILROAD CROSSTIES

White fir (p. 2) furnishes only a small fraction of 1 percent of the crossties purchased annually (*26*). The 1927 census reports the purchase by steam railroads of about 70,000 white-fir crossties, about

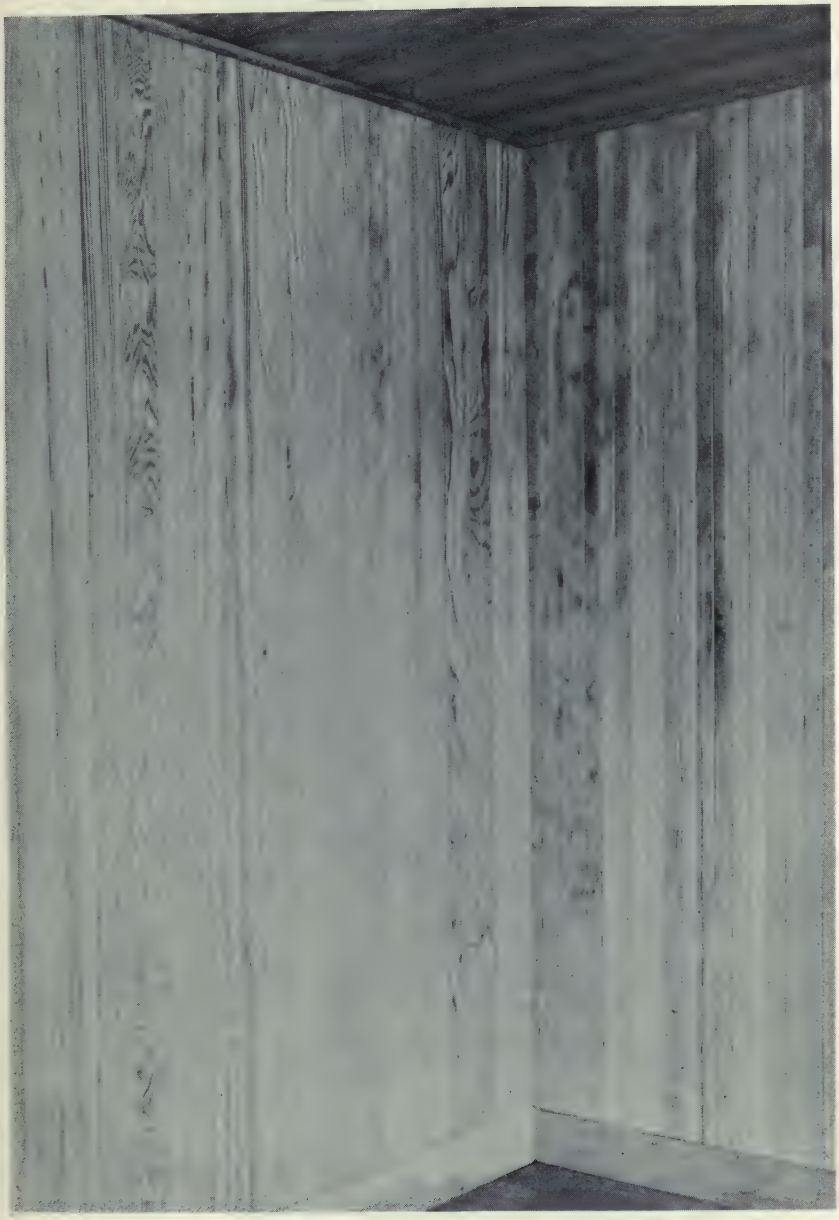
three fourths of which were treated with preservatives. In addition many were used by mills in their logging railroads and not reported.

Three strength properties are of special importance in appraising the mechanical properties of woods for crossties (*12*). These three properties—bending strength, hardness, and compressive strength—have been combined into a composite tie strength figure that gives an index of the suitability from the strength standpoint. Figure 31 compares the composite tie strength of white fir (*Abies concolor*) with that of a number of important tie woods. The composite tie strengths of white fir (*A. concolor*) and lowland white fir are about the same and are intermediate between the hemlocks, which are slightly higher, and the spruces, which are slightly lower. The composite tie strength of white fir is sufficient to meet the strength requirement of ties in main-line track, provided the ties are properly protected by tie plates.

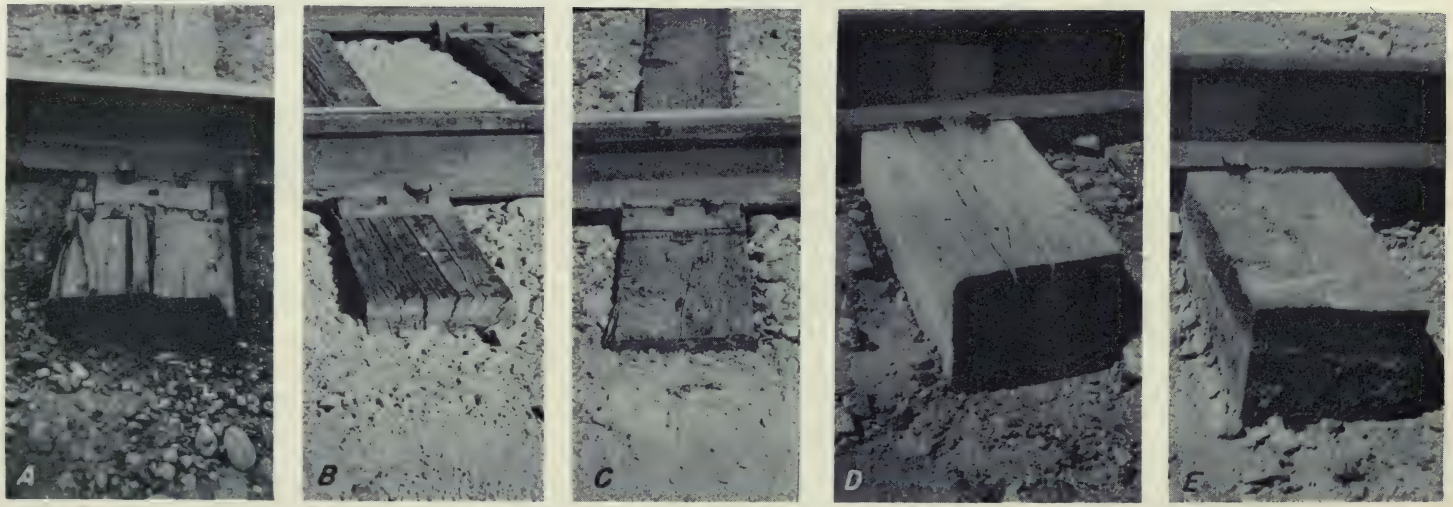
FIGURE 28.—White-fir timber and ties in trestles of logging railroad. White fir is often used untreated in logging roads where only a comparatively short life is required.

Unless treated with a preservative, white fir cannot be used successfully for ties in permanent track because of its low decay resistance. Both heartwood and sapwood are difficult to treat, being similar in this respect to Engelmann spruce. Experiments, however, have demonstrated that white-fir ties can be treated successfully (*10*). Untreated white-fir ties are extensively used in logging railroads because the life of such lines is short, and untreated white fir ties will generally last longer than the logging road is required.

Service records on about 14,000 white-fir ties are contained in table 24. An analysis of the service records shows that white-fir ties treated with either zinc chloride or creosote check badly. However, even though checked the ties treated with creosote, table 24, group 4, have given 13 years' service in main-line track under heavy traffic, and about 98 percent are still in place (pl. 10). The ties treated with zinc chloride, but no fuel oil, table 24, groups 5, 6, and 7, have only been in service about 7 years, but a high percentage are still in place. They,



WHITE FIR MOULDING, SIDE WALL, AND BASEBOARD IN NATURAL FINISH.
The figure is sufficiently pronounced to give the effect desired in natural finishes on softwoods.




THE USE OF FUEL OIL ALONG WITH PRESERVATIVES HAS DECREASED CHECKING IN WHITE FIR TIES.

A, Creosoted white fir ties after 13 years' service. Though badly checked and split few ties have been removed. B, Creosoted white fir ties after about 5 years' service. While none of the ties have been removed from the test track they are badly checked and split. C, White fir ties in the same track and same period as B, but treated with a mixture of creosote, coal tar, and fuel oil. In excellent condition, practically no checking or splitting. D, White fir ties treated with zinc chloride after about 4 years' service. In fair condition. Some checking and some plate wear has taken place. E, White fir ties treated with zinc chloride and fuel oil. In good condition. Some checking, but not so much as ties in D, which have been in same track during same period of time.

like the creosoted ties of group 4, are badly checked. The ties of all groups are in a track where conditions are favorable to checking.

Where fuel oil was used in combination with the zinc chloride or creosote the ties are in good condition. Fuel oil used along with the preservative appears to reduce the checking materially (pl. 10). Groups 1, 2, and 3 of table 24 in which fuel oil was used with creosote are all in good condition with practically no checking or splits after 7 years' service. Likewise, the ties in group 8 of table 24 where fuel oil was used in combination with zinc chloride are in excellent condition after 7 years' service. On the other hand, where zinc chloride was used without fuel oil, groups 5, 6, and 7, the ties have checked and split badly. It appears, therefore, that the trouble from checking and splitting of white fir ties can be reduced by the use of fuel oil. The ties on which this conclusion is based have not been in service long enough to permit an estimate of the increased life that will result from the use of fuel oil where used with preservatives nor can the conclusion be considered final on such a short period of service.

FIGURE 29.—White-fir posts, girders, and joists in heavy mill construction in a bakery in California after 5 years' service. Little or no checking and twisting have taken place in straight-grain side cut pieces. The worst checking which has occurred is shown in the girder. The timbers on the whole show very little checking despite the combination of hot, dry climate with extreme artificial heat.

### FURNITURE

The properties of white fir limit its use in furniture. Lack of color, small percentage of clear lumber, and the finishing characteristics prevent its use in expensive or highly polished furniture, except in concealed parts. Its light weight, freedom from resin, ease of working, stability, painting, and gluing characteristics adapt it to use as frames of overstuffed furniture, concealed parts of all types of furniture, and for furniture which is to be painted. Its properties also indicate it would make a good core for veneer panels. Only a small amount of white fir is now used for furniture. It is made chiefly into book racks, built-in cabinets, flower stands, benches, ironing boards, and similar articles to be used unfinished, stained, or painted. It is particularly suitable for shelves, drawers, and bins where foodstuffs are stored because of the wood's freedom from odor and pitch.

There is little prospect of any material increase in the use of white fir for furniture. There are a number of woods available that can be used satisfactorily in the same types and for the same parts of furniture as white fir. Many of these woods are grown nearer the large centers of furniture production than white fir and therefore make the entrance of white fir into this field difficult. The best prospects of increasing the use of white fir for furniture are in California and the Inland Empire.

FIGURE 30.—This heavy tongue-and-groove No. 1 Common white fir roofing has given good service under the severe conditions imposed by a laundry in a hot, dry climate.

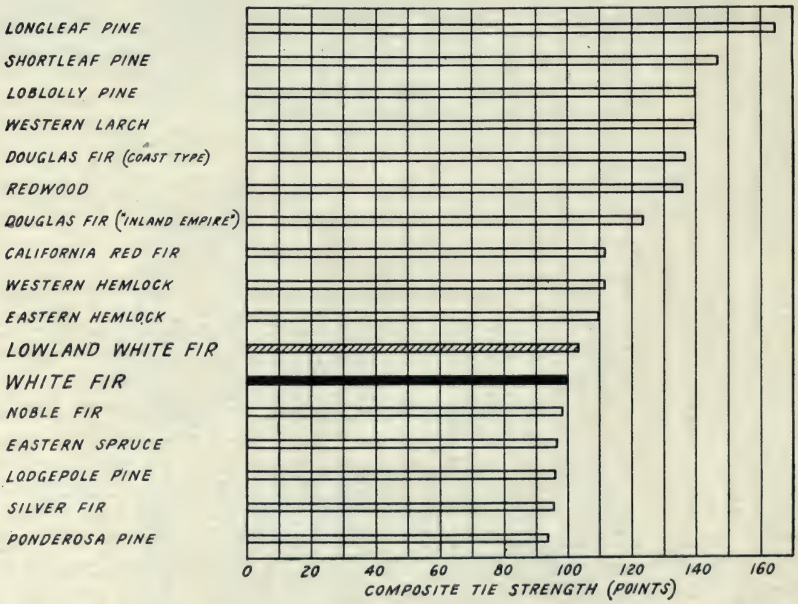



FIGURE 31.—Composite tie strength of white fir (*Abies concolor*) compared with that of a number of other species. The comparison is based on a combination of the three strength properties most important in ties.

TABLE 24.—*Service records of white fir and Engelmann spruce ties treated with preservatives* [1]

| Group | Species | Treating process | Preservation and absorption | Ties | Location | Date set | Approximate service at last inspection [2] | Traffic | Rail weight | Removals | Cause of removal | Condition of ties in tract at last inspection |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Pounds per cubic foot* | *Number* | | | *Years* | | *Pounds* | *Number* | | |
| 1 | White fir | Lowry | 3.6 creosote, and 8.4 fuel oil. | 782 | Idaho | May 1924 | 7½ | Medium | 90 | None | | Excellent. Slight rail cut at joints. |
| 2 | White fir and Engelmann spruce. | do | 8.6 creosote, and 0.4 fuel oil. | 3,131 | do | March 1924 | 7½ | do | 90 | None | | Do. |
| 3 | do | Full cell | Creosote, coal tar, and fuel oil.[3] | 720 | do | December 1923 | 8 | Heavy | 100¼ | None | | Excellent. Rail cut on outside of curve. |
| 4 | Lowland white fir | Lowry | 9.1 creosote | 200 | Montana | October 1915 | 13 | do | 100 | 5<br>4 | Mechanical wear.<br>Eliminate plate trouble. | Fair condition. Considerable checking and splitting. Some plate wear. |
| 5 | White fir and Engelmann spruce. | Burnett | 0.5 zinc chloride | 3,197 | Nevada | December 1924 | 7 | Light | 90 | 140 | Decay | Very bad checking. Rotting very fast. |
| 6 | do | do | do | 2,915 | Idaho | April 1924 | 7½ | Medium | 90 | 1 | Broken | Fair. Considerable checking and rail cutting. |
| 7 | do | do | do | 782 | do | December 1923 | 8 | Heavy | 100¼ | 40 | Checking and shatter. | Bad. Depreciating rapidly on account of checking and shatter. |
| 8 | do | Burnett (two-movement). | 0.5 zinc chloride, and 3.5 to 4 fuel oil. | 3,166 | Nevada | December 1924 | 7 | Light | 90 | None | | Excellent. |

[1] Compiled from 1930 Proceedings of American Wood-Preservers' Association (*2*).
[2] Last inspection on all groups except group 4 made October 1931 by G. W. Lorenz, of the Union Pacific System. Last inspection of group 4 made in 1928 by Forest Service.
[3] Absorption not reported. Treatment 30 percent creosote, 7.5 percent coal tar, and 62.5 percent fuel oil.

#### REFRIGERATORS

About 500,000 board feet of the western true firs (p. 2) are used annually for refrigerators. The properties of the wood that adapt it to this use are lack of odor, freedom from resin, light weight, thermal insulating properties, and ease of working. White fir may be used for the same parts of refrigerators as those made from spruce.

#### OTHER INDUSTRIAL USES

Small quantities of the western true firs are used in wooden ware, novelties, signs, car construction, instruments, silos, and tanks. The reported consumption of the western true firs in all these uses totals less than 100,000 board feet annually. All of these uses except car construction are comparatively small consumers of wood, and there is little likelihood of any of them furnishing a market for a considerable quantity of white fir. The total amount of softwood used by these industries in 1928, excepting car construction, was less than the white fir lumber cut for that year.[13] The heavier and stronger softwoods are preferred for most car-construction and repair work, douglas fir and southern yellow pine furnishing over 90 percent of the softwoods used. White fir is used for special parts of cars, such as lining for refrigerator cars and running boards on the top of freight cars.

#### REPORTED MISCELLANEOUS USES FOR WHITE FIR

A partial list of miscellaneous uses for white fir (p. 2) has been compiled by the Forest Service. Some of these uses have been discussed, others have not, either because of lack of knowledge of their required properties or because their requirements are enough like some uses already discussed for the comparison and analysis to apply in part or with slight changes. The list may be useful as a reference and indication of possible markets that might be developed. It should be remembered, however, that the fact that a species of wood has been used for a purpose does not indicate that it is the best wood for the purpose. In fact, a brief inspection of the list will reveal a number of uses for which other species are obviously better suited than white fir.

Altars, church
Appliances, laundry
Backing, furniture
Backs, sign, and dresser drawer
Baseboards
Baskets, candy, fruit, and veneer
Batens
Beams, railroad car brake
Benches
Blinds
Boards, barn, base, trim, and roof
Bodies, automobile and buggy
Bottoms, show case
Boxes, food, and canned goods
Boxes, heavy shipping
Broom handles
Brackets, cornice
Buckets
Cabinets, built-in and kitchen
Car, decking, siding, lining, and strips
Cars, electric
Cases, packing, piano, shipping, and shoe
Casing, house
Caskets and outside boxes
Ceiling, boat
Clapboards
Concrete forms
Construction, car
Cooperage, slack and tight
Cores, veneer
Corners, interior house base trim
Crates, fruit and vegetable
Crating, furniture and granite
Cross arms, telephone and telegraph
Dimension
Doors, house, and freight car
Drawers, furniture
Finish, car
Finish, house exterior and interior

[13] See footnote 12, p. 54.

Flooring and subflooring
Frames, suit case, door, refrigerator, and window
Freezers, ice cream
Gates, irrigation, car door, and fruit shipping
Girders
Goods, dairy
Handles, paint and sweeping
Heads, cheesebox
Instruments, musical
Joists
Lath
Legs, refrigerator and table
Lining, freight and refrigerator car
Logs, house
Lumber, rough
Matches
Moulding, house
Newels
Novelties
Oars, boat
Pails
Partitions
Parts, vehicle
Pipes, water
Planking, bridge, platform, and warehouse
Plates, house
Poles
Posts
Pulp, paper
Radio, aerial posts
Rafters
Railing
Refrigerators and kitchen cabinets
Roofing, freight car
Sash, doors, blinds, and window
Scaffolding
Shade rollers
Shakes
Sheathing
Shelves
Shiplap
Shooks, box
Siding, bevel, two-lap, freight car, log cabin, and rustic
Silos
Slats, window shade
Staves, silo
Steps
Studs
Supplies, dairy, and apiary
Subflooring
Tables
Tanks, oil well and windmill
Timbers, small
Ties, railroad
Tops, furniture
Towers, cooling
Toys
Traps, lobster
Trays, raisin
Trunks
Vehicles
Windmill, tanks, and silos
Woodenware and novelties

### PULP AND PAPER

White fir (p. 2) is admirably adapted to the manufacture of pulp and paper (*29*). Both white fir (*Abies concolor*) and lowland white fir are readily reduced by any of the standard mechanical or chemical processes. With the standard sulphite process white fir produces an unbleached pulp of excellent color and strength. The fibers are somewhat coarser than spruce fibers, but the pulp is easily bleached. The pulp yield is between 45 and 55 percent on a weight basis. Sulphite pulp from lowland white fir requires 15- to 25-percent bleach, and that from white fir (*A. concolor*) requires 10 to 15 percent. Pulps suitable for use in news, wrapping, book, and other high grade printing papers can be produced from both species.

A very strong unbleached pulp is produced from white fir with the sulphate process. The yield of strong pulp is from 45 to 50 percent with lowland white fir and 48 to 53 percent with white fir (*A. concolor*). The pulp is suitable for high grade wrapping papers and fiber board. The yield of pulp for bleaching is 35 to 45 percent and 38 to 43 percent, respectively. Sulphate pulps from both woods require 20- to 30-percent bleach.

Both white fir (*A. concolor*) and lowland white fir produce pulp of excellent color and standard strength by the mechanical process. From 15 to 25 percent more power is required than for white spruce. The pulp is suitable for all uses requiring ground wood.

In spite of the excellent pulping properties of white fir there is no early prospect for the extensive utilization of the stands of white fir

in the Inland Empire and California for this purpose. Neither region has a local market for pulpwood. The availability of large quantities of mill and woods waste suitable for pulp production in the Pacific Northwest, the cost of logging white fir logs or woods waste, the problem of transporting pulp overland to markets at a cost which will enable it to compete with water-borne pulp from Washington and Oregon, and the initial investment required for construction of a pulp mill make it improbable that any appreciable quantity of white fir in California or the Inland Empire will be used for pulp production in the near future. Lumbermen and timber owners in making their plans for handling their white fir stands should not rely on the early development of a market for pulpwood as a panacea for the utilization problems presented by their white fir stands.

## SUMMARY

California and the Inland Empire have forests containing 50 billion feet of white fir (*Abies concolor*) and lowland white fir. These woods grow and are harvested along with other species. For a number of years existing conditions have made it difficult, if not impossible, profitably to market white fir lumber. On the other hand there are serious objections both from forest management and utilization points of view to leaving the trees in the woods.

The lumber is relatively new and little known to many wood users, especially in the eastern and middle-western markets. The entrance of white fir lumber into these markets has created a number of problems to users. Detailed information furnished here on the properties, characteristics, and use of the wood will aid the consumer in determining its suitability for various uses and in obtaining long and satisfactory service from it.

Existing markets were found to be adversely affected by prejudices against white fir lumber. Investigation showed that these prejudices were caused largely by the results of improper manufacturing and marketing practices, such as marketing of insufficiently seasoned lumber, substandard sizes, and poor or inadequate grading. Control of these factors is in the hands of the manufacturers. Application of the information presented here on seasoning, grades, and influence of substandard sizes on strength and serviceability will help in overcoming these prejudices. No profitable market for white fir lumber can be developed so long as these prejudices exist.

The solution of the problem of the timberland owners and foresters is closely tied up with the problems of the lumber manufacturer and the consumer. Any improvement in the markets and the use of white fir lumber or in the character of service it renders will materially aid in the solution of the forest problem. An adequate and profitable market for white fir lumber would solve the forest-management problem.

A profitable market cannot be established for white fir lumber so long as better known and stronger competitive woods which are more favorably situated as regards quality, quantity production, and markets are sold at a loss. However, the adverse lumber market existing for the last 5 years must change and with the change will come the opportunity for consumers, manufacturers, and foresters to apply the information here presented to the solution of the perplexing problems in use, marketing, and management of white fir.

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TECHNICAL BULLETIN No. 407 APRIL 1934

# GROWTH IN SELECTIVELY CUT PONDEROSA PINE FORESTS OF THE PACIFIC NORTHWEST

BY

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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## INTRODUCTION

Forests of ponderosa pine (*Pinus ponderosa* Lawson)[1] cover a larger total area than those of any other conifer of the western United States. They occur in all the States west of the Great Plains and are the prevailing forest cover in eastern Oregon, eastern Washington, and parts of Montana, Idaho, Utah, Arizona, New Mexico, California, and South Dakota. In eastern Washington and eastern Oregon alone the area in this type is estimated at close to 10,000,000 acres, or almost 40 percent of the entire forested area in the two States. Of this total about 7,500,000 acres is located in Oregon and about 2,500,000 acres in Washington. The national forests of the two States contain the following areas of ponderosa pine timber: Oregon, 3,095,000 acres

[1] Until 1931 the official common name for this species was western yellow pine.

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merchantable and 94,000 acres immature; Washington, 716,000 acres merchantable and 13,000 acres immature (*34*).[2]

According to Forest Service estimates made in 1930, ponderosa pine timber amounts to 15,000,000,000 board feet in Washington and 79,000,000,000 board feet in Oregon, forming 14 percent of the volume of timber of all species in the two States. This proportion is second only to that formed by Douglas fir. The ponderosa pine timber in Washington and Oregon constitutes about 38 percent of the entire stand of this species in the United States, estimated by the Forest Service in 1932 [3] at 250,000,000,000 board feet.

Between 1911 and 1925 the annual cut of ponderosa pine rose in Oregon from 186,000,000 board feet to 1,000,000,000 board feet, and in Washington from 185,000,000 board feet to 441,000,000 board feet. At the present time, the annual cut in average years may be estimated roughly at 1,000,000,000 board feet for Oregon and 400,000,000 board feet for Washington. The present average cut in the two States amounts to 47 percent of the total average national cut of the species. (An additional 37 percent is contributed by the two neighboring States of California and Idaho.)

The general extent of the ponderosa pine forests in the Pacific Northwest [4] is shown in figure 1.

## PURPOSE OF THE STUDY

The statistics just given indicate in a broad way the great extent of the ponderosa pine forests of Oregon and Washington and their industrial importance both to the two States themselves and to the Nation at large. If the industries dependent on these forests are to be perpetuated it will be necessary to adopt logging and silvicultural practices such as will provide against the present and potential forest lands' becoming depleted or unfit to produce further timber crops. The purpose of the present study is to answer questions on only one phase of this general problem, namely, the growth rates and yields that can be expected in managed ponderosa pine forests. This subject includes the producing capacity of forests that have been cut selectively and the relative practicability of different methods of cutting. The report gives rates of growth for reserve stands varying widely in volume, from those left by a practically clean cut to those constituting more than 50 percent of the original volume. It also provides means whereby the growth rates of uncut stands may be estimated. It discusses briefly the essential factors affecting the growth and yield of uneven-aged stands. It treats in some detail of the development of the single tree, showing the effect of such factors as tree class, site quality, and release distance.

## THE FOREST

Excellent descriptions of the characteristic forms of ponderosa pine forests in the Pacific Northwest and other regions have been given in previous publications (*11*, *16*, *26*, *28*, *31*, *36*). The typical ponderosa pine forest of the Pacific Northwest is fairly pure, fairly open, and many-aged. Over large areas it is absolutely pure. Among the more

[2] Italic numbers in parentheses refer to Selected References, p. 49.

[3] UNITED STATES DEPARTMENT OF AGRICULTURE, FOREST SERVICE. THE FOREST SITUATION IN THE UNITED STATES: A SPECIAL REPORT TO THE TIMBER CONSERVATION BOARD. 46 p. 1932. [Multigraphed.]

[4] "Pacific Northwest" in this bulletin refers to Washington and Oregon only.

common associates, which vary in importance in different parts of the region, are lodgepole pine (*Pinus contorta* Loudon), sugar pine (*P. lambertiana* Douglas), white fir (*Abies concolor* Lindley and Gordon), lowland white fir (*A. grandis* Lindley), Douglas fir (*Pseudotsuga taxifolia* (Lamarck) Britton), and western larch (*Larix occidentalis* Nuttall). Associates of lesser importance are incense cedar (*Libocedrus*

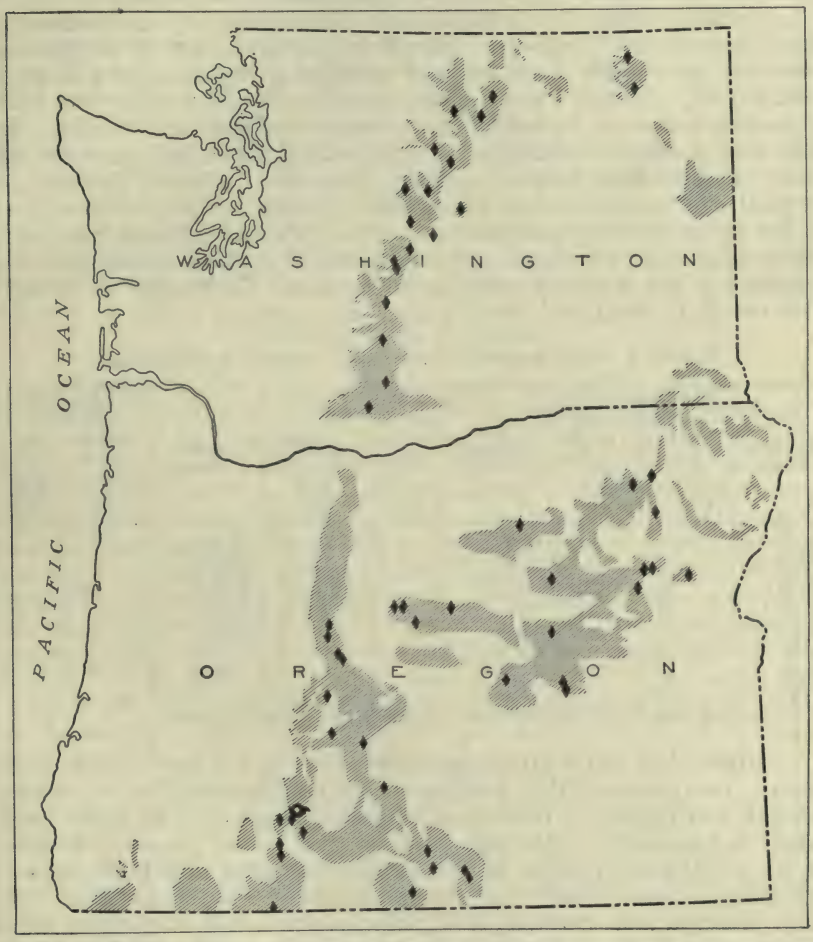



FIGURE 1.—Distribution of forests in Oregon and Washington in which ponderosa pine is the dominant species, and the location of areas studied in the investigation of growth. (Each dot represents one or more plots.)

*decurrens* Torrey), western red cedar (*Thuja plicata* D. Don), western juniper (*Juniperus occidentalis* Hooker), and Rocky Mountain red cedar (*J. scopulorum* Sargent).

Not all the component species listed are represented in equal degree in each part of the region; most of them occur to a varying extent and in some localities not at all. For instance, sugar pine and incense cedar are found only in the southern part near the Rogue River, Deschutes, and Fremont National Forests; western red cedar, only in the north on the Colville Forest; lodgepole pine, Douglas fir,

and white fir, throughout but in widely varying quantities; and western larch, from the Blue Mountains and the Mount Hood National Forest north. The mixture varies greatly between the lowest portion of the ponderosa pine zone, adjacent to the desert, and the uppermost portion, which adjoins a zone occupied by more mesophytic forest types.

The pure stands are estimated to contain approximately 75 percent of all the commercial ponderosa pine timber in the region.

Uneven age is another outstanding characteristic of the ponderosa pine forest of the Northwest. Single scattered mature or overmature trees are continually dropping out and being replaced by groups of young trees. On most areas every age class from 1 year to 350 years or more is present. In nearly every stand seedlings are starting, saplings and poles are established singly or in clumps, and advance bull pines [5] and mature and overmature trees are scattered throughout. Typical age composition is illustrated in table 1. The counts given in the table are not complete, since they do not include the young unmerchantable trees and the reproduction classes, which may far outnumber the trees of merchantable sizes. A number of stumps with rotten or fractured centers, also, are omitted.

TABLE 1.—*Age composition of typical ponderosa pine stands*

| Age class (years) | Number of stumps counted [1] | | Age class (years) | Number of stumps counted [1] | | Age class (years) | Number of stumps counted [1] | |
|---|---|---|---|---|---|---|---|---|
| | Area of 40 acres near Embody, Oreg. | Area of 26.17 acres near Bend, Oreg. | | Area of 40 acres near Embody, Oreg. | Area of 26.17 acres near Bend, Oreg. | | Area of 40 acres near Embody, Oreg. | Area of 26.17 acres near Bend, Oreg. |
| 60- 79 | ---------- | 1 | 260–279 | 23 | 83 | 440–459 | | 8 |
| 80- 99 | ---------- | 6 | 280–299 | 24 | 40 | 460–479 | | 4 |
| 100–119 | 6 | 18 | 300–319 | 18 | 19 | 480–499 | | 2 |
| 120–139 | 21 | 113 | 320–339 | 21 | 21 | 500–519 | 23 | 2 |
| 140–159 | 45 | 115 | 340–359 | 16 | 14 | 520–539 | | 2 |
| 160–179 | 37 | 9 | 360–379 | 5 | 17 | 540–559 | | 1 |
| 180–199 | 42 | 26 | 380–399 | 3 | 19 | 560–579 | | 1 |
| 200–219 | 27 | 32 | 400–419 | 7 | 9 | | | |
| 220–239 | 30 | 23 | 420–439 | 3 | 3 | Total | 400 | 698 |
| 240–259 | 49 | 110 | | | | | | |

[1] So far as possible, age class was determined for every stump present on the areas.

The fact that the relative representation of the age classes varies widely complicates the problems of management and cutting. Growth and mortality rates depend greatly upon age, as upon dominance and spacing. Marking practice that is not properly adapted to age composition leads to low rates of growth and high rates of mortality. Each stand is a special problem. In some stands the most practical and economical cutting method leaves a reserve volume of not more than 15 percent; in others it leaves 50 percent of the original volume.

Openness of the stand is a third characteristic of the usual ponderosa pine forest. Munger (*26*), Korstian (*18*), Krauch (*23*), and others in published and unpublished reports give instances of the relatively small number of trees per acre. In most of the stands in Oregon and Washington, trees of merchantable size number only 10 to 35 per acre. Behre (*7*, *8*) shows that the fully stocked even-aged stand at 150 years of age and on a site comparable to the average eastern

[5] In the Pacific Northwest ponderosa pine trees less than about 150 years of age are called "bull pine", a term comparable to the "blackjack" of other regions. They have rough black bark, pointed crowns, and a good rate of growth. Mature trees are commonly called "yellow pine", because of the yellowish color of their bark.

Oregon site contains about 104 trees 12 inches or more in diameter per acre. At 250 years a fully stocked even-aged stand on such a site contains about 80 or 85 trees of this size per acre.

In the even-aged stand, especially if it is fully stocked, the yields per acre are much higher than in the uneven-aged stand and there is a richer, denser flora and a thicker, more complete mantle of litter and humus. In the open uneven-aged stand, the action of the sun and wind hinders the development and continuance of such conditions.

Much of the ponderosa pine timber forms an intermediate type between mixed coniferous forests and desert. Although the pine can grow where the annual precipitation is as low as 17 or 18 inches, heavy mortality sometimes occurs locally during periods of drought. Previously the openness of the stands was considered to be principally the result of damage by fire and insects. The experience of the past few years has shown that drought is an equally important cause. The even-aged stand is less likely to occur on areas where rainfall is deficient than in the upper ranges of the pine belt next to the areas occupied by the mixed conifer type, where rainfall is not a limiting factor.

## METHODS OF CUTTING

Ponderosa pine, like other pines in general, responds well to many different silvicultural practices. At the beginning of national-forest management in the ponderosa pine type, the Forest Service adopted a type of cutting (*10*) that approximated a heavy grade of selection cutting. In different regions and at different times the cutting had characteristics of tree selection, of group selection, and of shelter-wood cutting. Marking instructions often stipulated that the faster growing trees and the trees less subject to windfall and insect damage be left. Emphasis was placed now and again upon one consideration or another such as spacing or type of tree, but in essence the principle remained the same. At present, in uneven-aged ponderosa pine stands on the national forests and the Indian reservations a system of partial cutting is employed that leaves from 15 to 30 percent of the merchantable volume for accelerated increment and insurance of seed supply and as the basis of a later cut after an interval of 40 to 75 years. A stand cut according to this system is shown in plate 1.

Cuttings made on privately owned land have in many instances constituted an unintentional selection cutting or culling. Several lumber companies have recently raised their diameter cutting limit and as a result are leaving reserve stands that, although of a lighter grade than those left under Forest Service practice, will form the nucleus of a later cut.

Careful protection of partially cut stands from fire assures a future merchantable stand, the time of the next cut depending largely upon the volume of the original reserve stand and upon market conditions.

The Forest Service cuttings just described will be called selection cuttings in the following discussion, although in a strict sense they cannot be so classified. This method of cutting will result in elimination of the older age classes within one or two cycles, conversion to younger and younger ages, and, probably, final transition into an even-aged stand. Increasing the percentage of reserve volume will postpone this final conversion; but unless present marking practice is greatly modified, a true selection forest with a wide range of age classes will not be maintained indefinitely.

The heavier the cut, the younger and the smaller will the reserve trees be. The average growth rate will be greater, because of the more responsive characteristics and increased growing space of the individual reserve trees. On areas heavily cut, however, the total volume growth per acre may not be sufficient to permit a later cut early enough or large enough to be profitable. In order to plan a cutting operation with a view to producing a successful later cut, one must be able to estimate the growth of the trees and the yields per acre.

## METHODS USED IN FORMER STUDIES OF GROWTH IN SELECTIVELY CUT STANDS

Since the usual selectively cut forest of ponderosa pine is complex in character, with various age classes, tree classes, spacings, and increment and mortality rates, the prediction of its growth and yield is not a simple and clear-cut process. A number of methods have been used, each having certain distinct advantages and also certain disadvantages. These methods, which are more or less interrelated and all of which are based on measurement of the single tree, can be grouped under four general headings:

(1) Permanent sample plots, as used by Dunning (*13*), Korstian (*18*), and Krauch (*23*).
(2) Diameter accretion. Krauch (*20, 22, 23*).
(3) Growth percentage. Hanzlik (*17*), Dunning (*12*).
(4) Reserve-stand growth, based upon reconstructed temporary sample plots. Meyer.[6]

Although the permanent sample plot method gives the most accurate information for small areas and this information is directly applicable to areas where conditions are similar, it requires long periods to yield reliable results. Prolonged growth cycles and epidemics must be experienced before average effects are determinable. In addition, permanent sample plots at the most can actually represent only a small portion of the total region. It would be an enormous if not impossible task to cover by this method all the essential varieties of condition and stocking. Besides, if successful management plans are to be laid it is imperative to make the growth calculations at the present time, before the stands are cut.

The diameter-accretion method can be based upon permanent sample-plot data, but can equally well be based upon increment borings. To apply this method, a stand tally is needed. The more detailed the tally, the better will be the result, because trees that are of the same diameter class but differ as to age, dominance, and crown class grow at different rates, respond differently to release, and vary in mortality.

Growth-percentage methods, although they appear to be among the simplest, have a number of weaknesses and are opposed by many investigators. Growth percentages can be applied either to stand tallies or to the stand as a whole. One of their weaknesses is that with variation in size of tree a growth percentage comes to mean totally different absolute volume growth. For small fast-growing trees the growth-percentage curve falls so rapidly that a highly inaccurate result is obtained unless the time and size elements are very carefully considered.

[6] MEYER, W. H. PRELIMINARY ALINEMENT CHARTS FOR DETERMINING GROWTH IN SELECTIVELY CUT STANDS OF WESTERN YELLOW PINE. Pacific Northwest Forest Expt. Sta. Forest Research Notes, No. 6, 9 p., 1931. [Mimeographed.]

Each of the four methods outlined has advantages over other methods at certain times and in certain places. For this reason the basic tables of growth rates of the single tree are included in this report, in the section beginning on page 37.

## METHODS USED IN THIS STUDY

In the present study an attempt is made to incorporate the virtues of several methods. In the initial computations diameter-accretion data, stand tables, plot records, and the like were combined. The result was a compound set of average values which show growth and yield, on the acre basis, according to the volume of the reserve stand. Then an analysis was made, one by one, of the factors that cause a departure of growth from the average, and methods were developed of correcting growth and yield estimates for these factors.

The basic data of this study were gathered in the course of the field seasons of 1928, 1929, and 1930, in eastern Oregon and eastern Washington. Measurements were made on 179 temporary sample plots in selectively cut stands. The location of each group of sample plots used in the study is given in figure 1 and in table 2, which gives also their acreage and their distribution as to site quality and age of cutting. The plots were located in representative stands scattered from southernmost Oregon to northernmost Washington and from the Cascade Range to the eastern boundaries of the two States. The extreme southwestern part of Oregon was excluded from the study because the ponderosa pine stands occurring there are of a different character from those typically occurring under average conditions in the central and eastern portions of the States, resembling rather the mixed pine forests of northern California.

TABLE 2.—*Summary of data by locality and site quality of plots and by age of cuttings*

DISTRIBUTION OF PLOTS BY LOCALITY

| State | Vicinity of— | Number of plots | Acreage of plots |
|---|---|---|---|
| Oregon | Deschutes National Forest | 31 | 45.76 |
| | Rogue River National Forest | 25 | 42.07 |
| | Fremont National Forest | 35 | 43.13 |
| | Ochoco National Forest | 13 | 18.75 |
| | Malheur National Forest | 6 | 10.00 |
| | Whitman National Forest | 18 | 39.75 |
| | Umatilla National Forest | 4 | 10.25 |
| Washington | Yakima Indian Reservation | 2 | 6.50 |
| | Snoqualmie National Forest | 18 | 35.60 |
| | Wenatchee National Forest | 15 | 37.00 |
| | Chelan National Forest | 9 | 28.75 |
| | Colville National Forest | 3 | 10.25 |
| Total | | 179 | 327.81 |

DISTRIBUTION OF PLOTS BY SITE QUALITY AND BY YEARS SINCE CUTTING

| Years since cutting | Number of plots, by site quality | | | | |
|---|---|---|---|---|---|
| | II | III | IV | V | Total |
| 10–19 | 4 | 9 | 34 | 13 | 60 |
| 20–29 | | 7 | 31 | 16 | 54 |
| 30–39 | | 6 | 26 | 9 | 41 |
| 40–49 | | 3 | 11 | 2 | 16 |
| 50–59 | | | 7 | | 7 |
| 60–69 | | | 1 | | 1 |
| Total | 4 | 25 | 110 | 40 | 179 |

The plots were so chosen as to represent the greatest possible variety of reserve-stand conditions, on the assumption that the combination would result in data expressing general conditions. Each plot was chosen arbitrarily to represent a certain condition, and not as a sample of average conditions for the area of which it was a part.

The sampling was restricted almost entirely to site qualities III, IV, and V. Site quality VI was omitted from the analysis because no suitable cutting areas representing this quality were found.

On each plot the growth of each tree was analyzed separately by means of increment borings. Detailed descriptions and measurements were recorded for almost 6,000 trees, including such items as diameter, total height, age, and diameter growth by 10-year intervals from 30 years before the cutting to the date of examination. A stand map was prepared, locating all trees and stumps and also the reproduction. The board-foot and cubic-foot volumes and basal area of every tree were computed for every decade after cutting and the plot volumes reconstructed. From these plot data, yield alinement charts were constructed by a method similar to that outlined by Bruce and Reineke (*9*) for stand tables.

Since the alinement charts represented the elements of age and volume only, the effect of site quality, structure, and other factors remained to be determined. For this purpose the percentage differences between actual volumes at every decade and volumes estimated on the basis of the growth charts were subjected to statistical computation.

Several elements of error are undoubtedly present. But after the accumulation of data from a large number of plots and thousands of borings some of these elements become compensative; and in this instance none of them can have led to overestimation of yields, because a conservative view was adopted where there was any choice. The results of the study are intended for use in the Pacific Northwest, and in other regions having similar conditions, until the time when permanent sample plots have given reliable and consistent results.

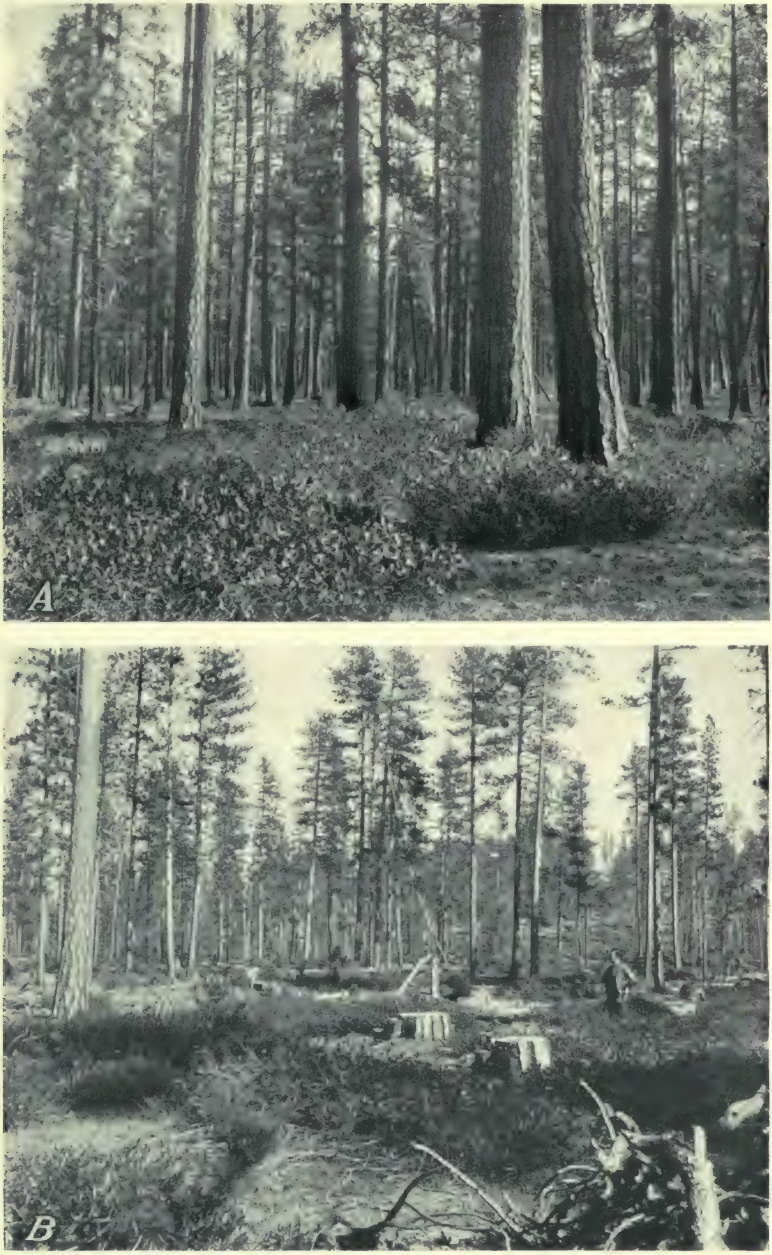
## FACTORS INFLUENCING RATE OF GROWTH IN SELECTIVELY CUT STANDS

In a pure, even-aged stand only site quality, age, and stocking need be considered in predicting growth; but in a many-aged cut-over stand a number of other influences demand attention. The following factors will be discussed here, in the order given:

1. Site quality.
2. Reserve volume.
3. Tree class and stand structure.
4. Spacing and release.
5. Composition.
6. Growth cycles.
7. Length of cutting cycle.
8. Mortality.

### SITE QUALITY

Every tree species is capable of enduring a wide range of site qualities, but even in the case of trees originating from the same parent tree the sizes attained depend largely upon the kind of soil, the moisture and drainage conditions, and other site features. In the ponderosa pine forests of the Pacific Northwest, the site quality of forest




*A*, Typical virgin forest of ponderosa pine in central Oregon. The four trees in the foreground are overmature, hence slow growing and less responsive to release than younger trees. Normally they would be removed in selection cuttings. *B*, The same forest 5 years after cutting. One of the four overmature trees was left, in order not to create a large blank in the reserve stand. The appearance of this area is similar to that of a large aggregate area of cut-over national-forest land.

*A*, Unusually heavy reserve stand of 20,000 board feet per acre, on site quality IV. Such a stand on a site of this quality usually grows at the rate of 230 board feet per acre per year. *B*, Very light reserve stand, of about 500 board feet per acre, on private land. Practically all the trees are young and fast growing; 90 percent are of tree classes 1 and 2. With this stand structure (p. 12) the growth may be expected to be about 30 percent above the rate of 35 board feet per acre that is average for this site (IV) and stocking.

lands bearing mature timber crops is judged by the average height of the mature dominant trees. Figure 2 illustrates the classification. For the young age classes, the curves are based upon observations made by C. E. Behre in yield studies of even-aged stands in northern Idaho (*7*, *8*) and confirmed through similar unpublished studies by the author in Oregon and Washington. The central values of site qualities I, II, III, IV, V, and VI correspond to site indices 127, 112, 96, 80, 65, and 51 of Behre's classification, site index being the average height of dominant and codominant trees of even-aged stands at 100 years.

For estimating the site quality of lands occupied by uneven-aged ponderosa pine forests, the procedure is as follows:

Measure the total height, in feet, of 15 to 30 mature, dominant trees of Dunning's tree class 3 (*14*). Average these values and enter

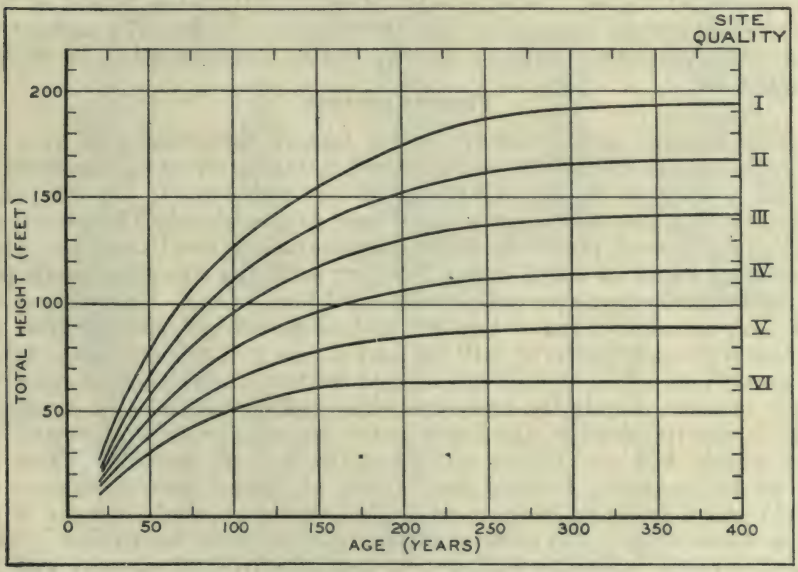



FIGURE 2.—Site-quality classification of ponderosa pine lands, based upon average total height of dominant trees.

the average value upon the chart at the approximate average age of the trees. For mature trees exact age is not necessary, since height changes little after maturity is reached. The curved line nearest to the point entered upon the chart indicates the site quality. For instance, an average height of 110 feet at maturity—about 300 years—indicates site quality IV.

For immature even-aged stands, the procedure is slightly modified. In this case the average heights of the dominant and codominant trees are taken and the exact age of the stand is found by means of stump counts or by increment borings. The height is then entered upon the chart at the determined age. If a certain even-aged stand is 75 years old and the dominant and codominant trees average 78 feet, for instance, the site quality is III.

The relations shown in figure 2 are expressed in terms of merchantable height in table 3.

TABLE 3.—*Site qualities of ponderosa pine land as defined by total height or by merchantable height of average dominant tree*

| Site quality | Total height | | Merchantable height at maturity, in 16.3-foot logs |
|---|---|---|---|
| | At 100 years | At maturity | |
| | *Feet* | *Feet* | *Number* |
| II | 112 | 166 | 8 to 9. |
| III | 96 | 138 | 7. |
| IV | 79 | 114 | 5 to 6. |
| V | 65 | 89 | 3 to 4. |
| VI | 51 | 63 | Less than 3. |

In Oregon and Washington the most common site qualities of pine lands are III, IV, and V. A little land of site quality II is found in southern Oregon, and some land of site quality VI is found in the poorest situations throughout the two States. At least 75 percent of the entire pine-forest area in the two States is estimated to be of site quality IV.

### RESERVE VOLUME

The volume of the reserve stand largely determines its rate of growth and its yield. On one plot, for instance, on which the reserve stand amounted to only 4,617 board feet per acre, in the 16 years after cutting the annual growth per acre averaged only 71 board feet. On a neighboring plot with the same general site conditions but with a reserve stand of 9,540 board feet per acre, the annual growth per acre during the same period averaged 134 board feet. The volume on the first area increased at the rate of 1.54 percent a year and that on the second at the rate of 1.40 percent a year. The percentage rates of growth are on the whole most rapid for the stands of small reserve, since in these stands the trees are wider spaced and usually younger. The larger the reserve, the lower is the percentage rate of growth on the whole, but the higher the absolute rate of growth. Thus in 30 years' time the average stand with an initial reserve volume of 2,000 board feet will increase to 4,000 board feet, while a stand with three times that initial reserve will increase to 8,900 board feet. The stand volume increases in the first instance by 100 percent and in the second by only 48 percent, although the annual growth rate is 67 board feet in the first as compared with 97 board feet in the second. An example of a heavy reserve stand and one of a light reserve stand are shown in plate 2.

### TREE CLASS AND STRUCTURE

A system of classifying ponderosa pine trees that was introduced by Dunning (*14*) for California conditions has been generally adopted in the Pacific Northwest and other regions. It distinguishes seven types of trees, which are illustrated in figure 3. Dunning's descriptions of the different tree classes are as follows:

Class 1. Age class, young or thrifty mature; position, isolated or dominant (rarely codominant); crown length, 65 percent or more of the total height; crown width, average or wider; form of top, pointed; vigor, good.

Class 2. Age class, young or thrifty mature; position, usually codominant (rarely isolated or dominant); crown length, less than 65 percent of the total height; crown width, average or narrower; form of top, pointed; vigor, good or moderate.

Class 3. Age class, mature; position, isolated or dominant (rarely codominant); crown length, 65 percent or more of total height; crown width, average or wider; form of top, round; vigor, moderate.

Class 4. Age class, mature; position, usually codominant (rarely isolated or dominant); crown length, less than 65 percent of the total height; crown width, average or narrower; form of top, round; vigor, moderate or poor.

Class 5. Age class, overmature; position, isolated or dominant (rarely codominant); crown of any size; form of top, flat; vigor, poor.

Class 6. Age class, young or thrifty mature; position, intermediate or suppressed; crown of any size, usually small; form of top, round or pointed; vigor, moderate or poor.

Class 7. Age class, mature or overmature; position, intermediate or suppressed; crown of any size, usually small; form of top, flat; vigor, poor.

In the field, if the classification is observed strictly it may seem that a large proportion of the trees are border-line specimens. After a

FIGURE 3.—Tree classes in uneven-aged stands of ponderosa pine, as defined by Dunning.

little practice with an experienced estimator, however, the determination is easily made at a glance. In border-line cases age and vigor are given more weight than some of the other factors.

On site quality IV in Oregon and Washington, in the virgin stands tree class 1 has the best growth rate and is followed as a rule by the other classes in this order: 2 and 3, 4, 5 and 6, 7. In selectively cut stands, although the trees respond individually to release according to spacing, tree class, and diameter, the rank of tree classes as to growth is little changed from that in the uncut forest, being 1, 3, 2, 4, 6, 7, 5.

In rate of mortality, these tree classes have been ranked by Dunning for California conditions as follows, with the least susceptible first: 1, 6 and 3, 2, 5 and 4, 7. Studies by the Division of Forest Insects, Bureau of Entomology, discussed on pages 30–31, have revealed a more complicated ranking, shown in table 15.

The composite of the proportion of each of the seven tree classes in a stand is indicated in this report by the term "structure." A perfect expression of structure would cover all tree classes, but a compound factor of this nature would be too unwieldy for practical use. Thorough investigation of the influence of each tree class and of groups of tree classes upon the rate of growth of the stand has shown that the percentages of cubic-foot volume or of basal area contained

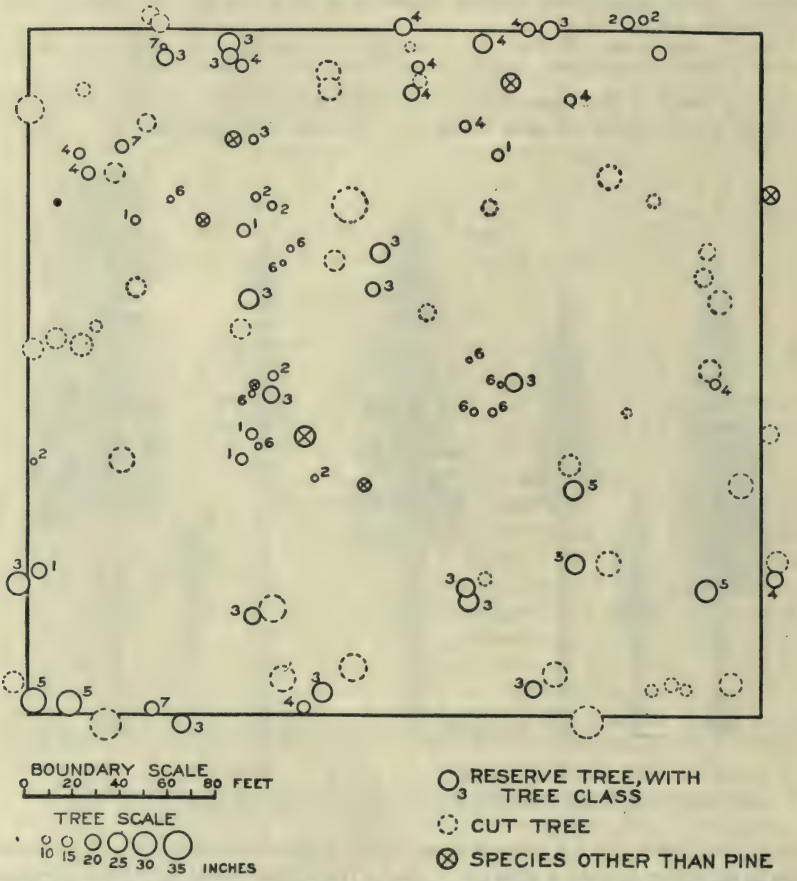

BOUNDARY SCALE
0 20 40 60 80 FEET
TREE SCALE
10 15 20 25 30 35 INCHES
RESERVE TREE, WITH TREE CLASS
CUT TREE
SPECIES OTHER THAN PINE

FIGURE 4.—Reserve stand unsatisfactorily spaced and containing an unusual percentage of old trees, which showed growth somewhat below average for selectively cut stands. Sample plot no. 52, Odessa, Oreg. Original stand per acre (of pine only), 24,600 board feet; original reserve per acre, 8,360 board feet; volume per acre 20 years after cutting, 10,833 board feet.

in tree classes 1 and 2 on the one hand and in tree class 3 on the other hand exert the most powerful influence upon volume growth next to site quality and total volume of the reserve stand. These two groups include three of the fastest-growing tree classes. The larger the percentage of tree classes 1 and 2 in relation to the percentage of all other classes, the faster is the growth. The larger the percentage of tree class 3 in relation to the percentage of all other classes, also, the faster is the growth, but in this instance the effect is less pronounced.

In this study, structure is expressed in terms of the percentages of the stand composed by these two groups of tree classes. The struc-

Cross section of the stem of a ponderosa pine tree released from competition by selective cutting in 1910, when it was 20 years old. During the first 2 years after release the thickness of the growth rings increased slightly. A marked acceleration in growth then began, and increased growth continued until the tree was cut in 1930.

ture expression 25–50, as an example, means that of the total cubic-foot volume or basal area of the stand 25 percent is composed of tree classes 1 and 2 and 50 percent of tree class 3.

### SPACING AND RELEASE

The effect of release upon the growth of ponderosa pine has been measured frequently (*12, 13, 14, 18, 22, 24, 26, 29*),[7] and the results stated both in absolute growth rates and in percentage of acceleration. For the purposes of this study percentage of acceleration is hardly to the point, since all the computations have been made in absolute values.

It must be remembered that the removal of part of the stand in the general vicinity of a given tree does not invariably constitute release and cause acceleration in the tree's rate of growth. To be susceptible of release, a tree must be in actual competition with other trees for moisture and nutrients.

The growth acceleration resulting from release varies somewhat according to the condition and vigor of the tree. The most vigorous trees respond almost immediately to a slight extent; their growth accelerates for about 5 years and then maintains a new level for several decades, unless other factors destroy the balance. A cross section of a ponderosa pine tree showing marked acceleration in growth after release appears as plate 3. Figure 4 shows a reserve stand containing an unduly large proportion of old trees and unsatisfactorily spaced, the growth of which in the 20 years following cutting was below average for selectively cut stands. Figure 5 shows in contrast with this a stand in which the trees reserved were principally immature or in an early stage of maturity and release was extraordinarily complete, and which in the 32 years following cutting grew at a rate much above average. Figure 6 illustrates the progress of growth in a stand that was selectively logged in 1898; of 10 sample trees, all except 1 responded to a certain degree within 2 years, and the growth rate increased rapidly for several years with variations between climatically favorable and unfavorable years. The marked decline in radial growth starting about 1917 was due not to a cessation of the effect

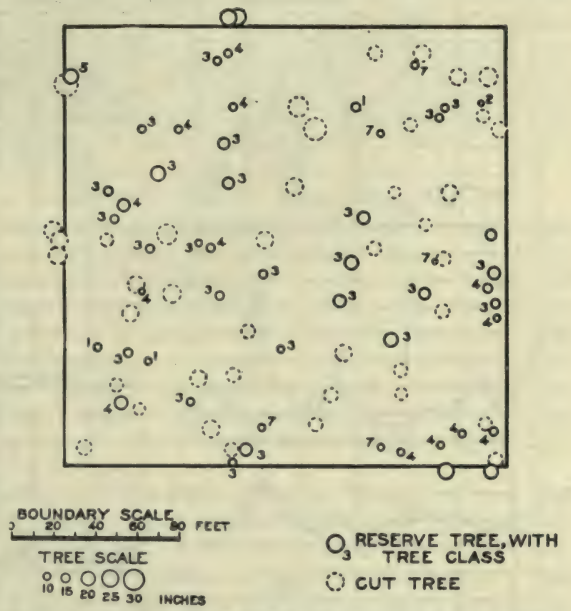



FIGURE 5.—Stand composed chiefly of immature and young mature trees, in which extraordinarily complete release conditions resulted in a yield far above average for selectively cut stands. Sample plot no. 128, near Starkey, Oreg. Original stand per acre, 27,128 board feet; original reserve per acre, 7,601 board feet; volume per acre 32 years after cutting, 14,760 board feet.

[7] MEYER, W. H. See footnote 6.

of release but to a period of generally unfavorable climatic conditions, which is reflected in the growth rates of ponderosa pine throughout the Pacific Northwest. In a period of average climatic conditions, growth increase due to release can be expected to persist for 40 years or more.

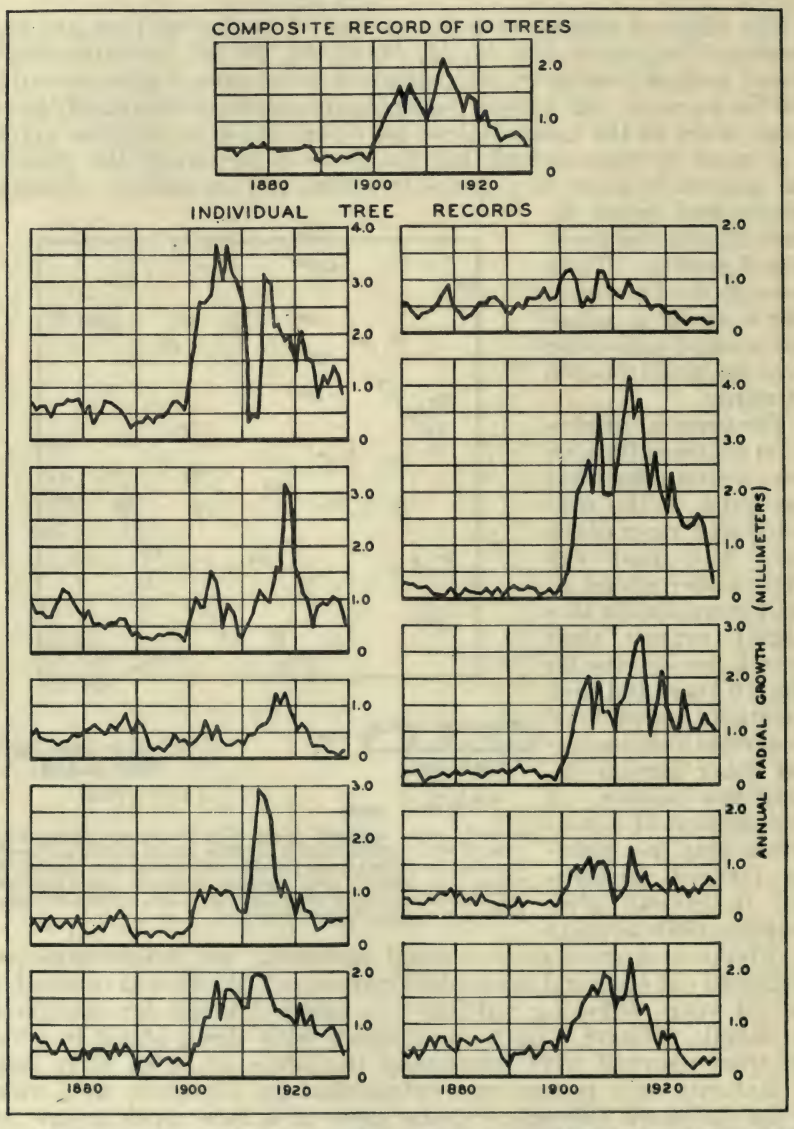



FIGURE 6.—Progress of growth following release in a ponderosa pine stand logged in 1898, as shown by the radial growth of 10 trees separately and combined.

Removal of a single sizable tree from a clump has a beneficial effect on the surrounding trees with which it has been competing directly for nutrients, soil moisture, and, to a lesser degree, light.

The distance to which release is effective varies somewhat with tree class and with site quality. In general (see table 21), trees that

have been liberated on one or more sides within a distance of 40 feet on site qualities III and IV show approximately the same acceleration in growth rate as other trees of the same class released on the same number of sides and within that distance. Acceleration is discernible in trees released at distances as great as 50 feet or sometimes even greater.

### COMPOSITION

Several of the species commonly found in mixture with ponderosa pine, such as white fir, Douglas fir, and sugar pine, grow faster than ponderosa pine, but do not respond so readily to release (*13*). Others, such as western larch, grow at approximately the same rate as ponderosa pine and still others, such as lodgepole pine and juniper, grow more slowly. The effect of mixture upon the accelerated growth rate of the stand depends therefore entirely upon what species contribute to the mixture. The tables developed in this study apply very well to the ponderosa pine of mixed stands in which other species constitute not more than 25 percent of the total volume, and their application even to the total volume of all species in such stands is well within the acceptable limits of error.

### GROWTH CYCLES

It is not an easy matter to evaluate climate and growth relationships, especially the occurrence, intensity, and extent of climatic cycles as shown by tree-ring patterns. So numerous are the factors that can affect the rate of tree growth, so involved is the history of a forest stand, that the final ring pattern of a single tree is highly individualistic. Tree-ring patterns record certain major events in the life history of the stand, but rarely agree throughout a stand in any marked degree. Only agreement in general ring-pattern characteristics in tree after tree and on area upon area can be taken as evidence of general climatic changes.

In searching for evidence of growth cycles in the ponderosa pine region of the Pacific Northwest it was impossible to cover all the available data, taken from some 8,000 increment cores; it was therefore decided to choose arbitrarily 24 localities representative of the region and in each of these to select a few cores of mature trees, usually 10, for examination. In case evidence of growth cycles was found, the plan was to endeavor to determine whether they were sufficiently distinct to affect yield predictions and how regularly they could be expected to recur during the interval between successive cuts. Whether a separate correction for climatic cycles had to be introduced into the growth predictions depended upon the results of this determination.

If this growth study had been made 10 years earlier, the importance of this information might not have been appreciated. Soon after the inception of the study, evidence was found of a major reduction in growth rate extending over a number of recent years. As more and more areas were investigated, it became increasingly certain that this retardation of growth was well defined over the two States. The period of retarded growth seemed in a general way to start about 1917; on some areas it did not begin until several years later, and on a very few areas the retardation was hardly observable. If this phenomenon recurs repeatedly, at regular or irregular intervals, as a phase of a natural sequence, yield predictions extending over a long span of years should take into account periods of slow growth as well as periods of good growth. The inclusion or noninclusion of the

period of slow growth therefore hinges upon the existence or nonexistence of growth cycles.

The method of dealing with the data is shown in figure 7. The curves shown in the chart indicate that there was a wavelike pro-

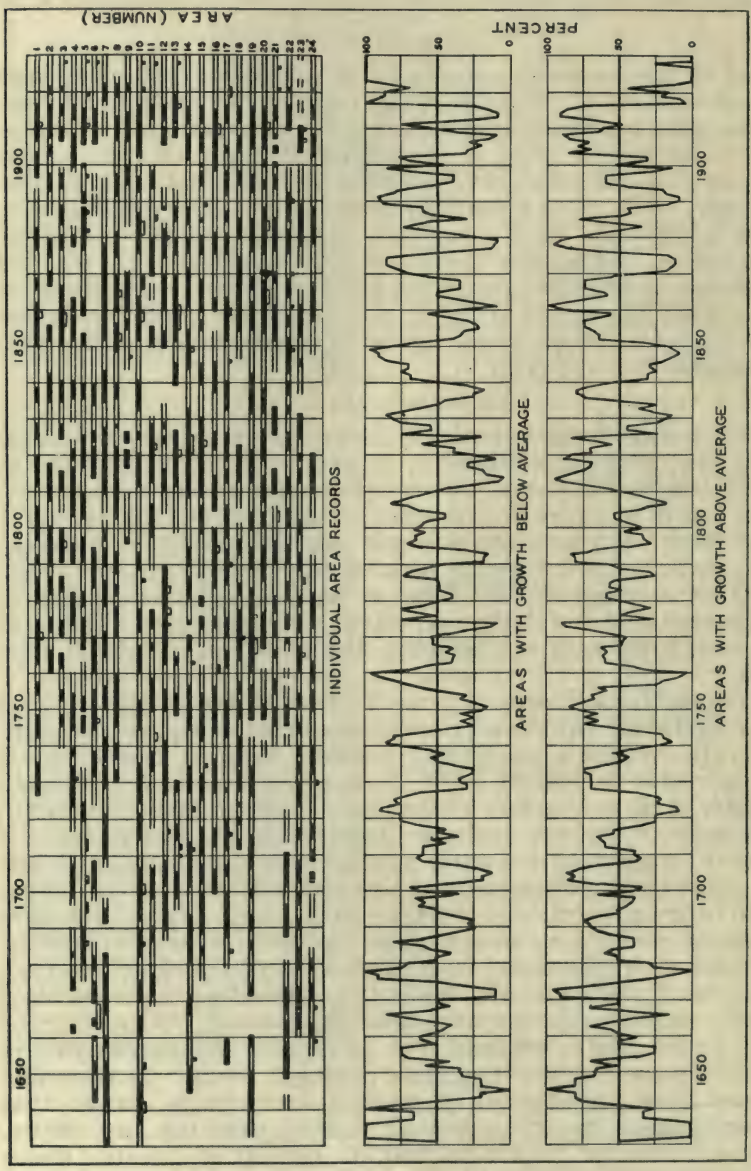



FIGURE 7.—Periods of poor and of good growth on 24 areas widely distributed through central and eastern Oregon and Washington. Black bars represent periods of good growth. Unfilled bars represent periods of poor growth. Blanks represent indeterminate growth. Curves represent occurrence of poor and of good annual growth, expressed in percentages of the whole number of plots for which periods of poor or good growth were determinable.

gression of good and of poor growth years. When more than 50 percent of the plots showed coincidental periods of good growth or of poor growth the phenomenon was considered significant. On this basis, major peaks of growth at intervals of 17 to 30 years were distinguished. These are listed in table 4.

TABLE 4.—*Peaks of good growth and of poor growth in ponderosa pine forests of Oregon and Washington*[1]

| Major peaks of poor growth | | | | Major peaks of good growth | | | |
|---|---|---|---|---|---|---|---|
| Approximate dates | Interval in years | Approximate dates | Interval in years | Approximate dates | Interval in years | Approximate dates | Interval in years |
| 1633 | | 1807 | 19 | 1645 | | 1814 | 21 |
| 1655 | 22 | 1831 | 24 | 1673 | 28 | 1838 | 24 |
| 1678 | 23 | 1849 | 18 | 1692 | 19 | 1861 | 23 |
| 1701 | 23 | 1873 | 24 | 1705 | 13 | 1878 | 17 |
| 1722 | 21 | 1891 | 18 | 1733 | 28 | 1908 | 30 |
| 1741 | 19 | 1924 | 33 | 1751 | 18 | | |
| 1760 | 19 | | | 1774 | 23 | Average | 21.9 |
| 1788 | 28 | Average | 22.4 | 1793 | 19 | | |

[1] Table based on increment-core data for 24 areas, representing in general 10 trees on each area.

The locations of the areas on which the increment-core data presented in figure 7 and table 4 were taken are as follows: 1, Pokegama, Oreg.; 2, Odessa, Oreg.; 3, Lakeview, Oreg.; 4, Lakeview, Oreg.; 5, Lakeview, Oreg.; 6, Lakeview, Oreg.; 7, Silver Lake, Oreg.; 8, Fort Rock, Oreg.; 9, Sisters, Oreg.; 10, Prineville, Oreg.; 11, Ochoco National Forest, Oreg.; 12, Malheur National Forest, Oreg.; 13, Austin, Oreg.; 14, Sumpter, Oreg.; 15, North Powder, Oreg.; 16, Starkey, Oreg.; 17, Heppner, Oreg.; 18, Yakima Indian Reservation, Wash.; 19, Wenas, Wash.; 20, Cle Elum, Wash.; 21, Wenatchee, Wash.; 22, Wenatchee Lake, Wash.; 23, Chelan, Wash.; and 24, Knowlton, Wash.

An average interval of approximately 22 years between major peaks of good growth or of poor growth is indicated. Each of these periods includes several subsidiary fluctuations. As compared with the cycle averaging 22 years, this minor cycle shows a much greater variation. Its recurrences are shown in table 5.

TABLE 5.—*General periods of good and of poor growth in ponderosa pine forests of Oregon and Washington*

| Approximate dates | Approximate duration, in years | Character of growth | Approximate dates | Approximate duration, in years | Character of growth |
|---|---|---|---|---|---|
| 1630–42 | 13 | Below average (except 1637–38). | 1776–79 | 4 | Below average. |
| 1643–53 | 11 | Above average. | 1780–85 | 6 | Above average. |
| 1654–59 | 6 | Below average. | 1786–88 | 3 | Below average. |
| 1660–63 | 4 | Above average. | 1789–94 | 6 | Above average. |
| 1664–67 | 4 | Below average. | 1795–1810 | 16 | Below average (except 1803–4) |
| 1668–74 | 7 | Above average. | 1811–26 | 16 | Above average. |
| 1675–87 | 13 | Below average (except 1684). | 1827–34 | 8 | Below average. |
| 1688–94 | 7 | Above average. | 1835–40 | 6 | Above average. |
| 1695–1701 | 7 | Below average. | 1841–51 | 11 | Below average. |
| 1702–7 | 6 | Above average. | 1852–68 | 17 | Above average. |
| 1708–12 | 5 | Below average. | 1869–75 | 7 | Below average. |
| 1713–16 | 4 | Above average. | 1876–81 | 6 | Above average. |
| 1717–27 | 11 | Below average. | 1882–94 | 13 | Below average (except 1885). |
| 1728–38 | 11 | Above average. | 1895–97 | 3 | Above average. |
| 1739–44 | 6 | Below average. | 1898–1902 | 5 | Below average. |
| 1745–55 | 11 | Above average. | 1903–16 | 14 | Above average. |
| 1756–62 | 7 | Below average. | 1917–30 | 14 | Below average. |
| 1763–65 | 3 | Above average (except 1768–70). | | | |

Tables 4 and 5 represent only general tendencies, evidence of which appeared on the majority of the 24 areas. The data presented in them are based on about 217 ring patterns, no one of which was exactly identical with any other. These data establish the fact that

a growth cycle having a duration of approximately 22 years occurs in the Pacific Northwest ponderosa pine region. This cycle tends to recur about three times during a 60-year cutting cycle, and should therefore be taken into account in growth estimates. It has been taken into account in this study. Hence the rates that were derived are adapted to long-term predictions. Should the term be short or overlap a partial cycle, the chances are that the prediction will be somewhat low, since the recent period of slow growth has been observed to be one of the most extreme in the entire record.

### LENGTH OF CUTTING CYCLE

The length of the cutting cycle, or the interval between cuts, has a subordinate effect upon the average rate of growth, since in a selectively cut stand where many trees have been released the growth rate reaches a maximum in the second decade after cutting and then gradually tapers off, approaching the rates previous to release. For instance, if a reserve stand of 2,000 board feet is held 30 years, the average annual increment will be 67 board feet; if it is held 60 years, the average annual increment will be only 60 board feet. (See table 8.) A reserve stand of 6,000 board feet over a period of 30 years will give 100 board feet a year, but over 60 years will give only 92 board feet a year. The decrease is much more evident when growth is expressed in diameter measurements, as in tables 18 and 19 or figure 11.

### MORTALITY [8]

The factors in growth rate thus far discussed determine gross yields. Since gross yields can be utilized fully in only a few cases, it is necessary to estimate mortality and net yield. Even casual observation in the various sections of the Pacific Northwest shows that the rate of mortality is highly variable. In some sections it is so high, at least at the present time, as to cause gradual depletion of the stand. In other sections it is remarkably low. Mortality is a local factor, to be evaluated each time a new area is examined. In part this variation is due directly to variations in the proportion of susceptible classes of trees in the stand. The fact that certain tree classes are more susceptible to insect damage than others has been shown by Dunning (*14*) and Krauch (*23*). It has been shown by Weidman (*35*), and by Smith and Weitknecht (*32*), that tall, full-crowned trees, and trees standing on exposed places or lee slopes, are more likely to be wind-thrown than others.

Surface fires take their toll in the destruction of seedling and sapling growth and in the butt scarring and subsequent wind-felling of large mature trees. Experience of the past few years has taught that recurrent drought alone causes immense damage, especially on areas near the lower limits of tree growth. Over and above these effects is the effect of climatic cycles on the vigor and susceptibility of trees. Mortality rates of the past decade are probably maximum rates, because of the severe climatic conditions.

In California, damage by insects alone has created doubt as to the advisability of leaving reserve stands on the poorer ponderosa pine sites, which are comparable to the average site in the Pacific Northwest. In the Pacific Northwest, insect damage to ponderosa pine is less severe. In this region, apparently, the climatic range of

[8] Mortality is discussed at greater length in a section beginning on p. 29.

the western pine beetle (*Dendroctonus brevicomis* Lec.), the most damaging of the western bark beetles, does not include the climatic range of ponderosa pine. North of the zone of *D. brevicomis* infestation, however, occasional heavy infestations of the mountain pine beetle (*D. monticolae* Hopk.) have been observed lapping over from lodgepole pine stands into stands of ponderosa pine.

Windfall is a more important factor in ponderosa pine mortality in the Pacific Northwest than it seems to be in any other region of the United States. In this region, it has been asserted (*32*, *35*), within the first 20 years after cutting as much as 25 percent of the volume may be eliminated by windfall. Even with this heavy loss, selection cuttings cannot be considered a failure. Most of the windfall occurs within the first 4 or 5 years after cutting, when some salvage is possible.

Fire can be controlled to a large extent in the ponderosa pine type, through suitable slash-disposal and other measures. Insect damage can be partially controlled by choice of trees for cutting and by systematic eradication of infested trees. Windfall can be partially controlled by removing the very tall, long-crowned trees and by cutting more heavily in exposed places than in protected places. It is plain that the mortality rates prevailing in virgin stands may be only a slight indication of the rates to which management may reduce the mortality in selectively cut stands.

## PREDICTING GROWTH OF SELECTIVELY CUT STANDS

The statistical method followed in this study leads to a simple procedure in predicting growth. By means of the stand-growth tables developed in the study the gross yield for any length of cutting cycle up to 60 years is predicted on the basis of the volume of the reserve stand, the percentage of the total volume in a few selected tree classes, and the site quality. In order to arrive at the net yield, a separate adjustment is made for mortality. The reproduction stand is considered by itself, since its condition is one of the most variable features of the ponderosa pine forest.

The steps in making growth predictions can be listed as follows:

1. The forest survey, determining—
   - *a*. Area, by types.
   - *b*. Site quality.
   - *c*. Reserve volume.
   - *d*. Structure.
   - *e*. Density of reproduction.
2. Estimating average gross yields.
3. Adjusting for site quality and structure.
4. Adjusting for mortality.
5. Adjusting for number of poles.

Each of these steps will be discussed in turn, and two examples will be given illustrating the necessary computations.

### THE FOREST SURVEY

The usual form of strip estimate, with slight modifications, forms the most satisfactory forest survey. Field data should be recorded separately for the various sites and types. A change in tally is not justified by a change in site or type affecting an area smaller than 20 acres. An open area such as a meadow or prairie should be treated as a separate type and in the final treatment such open areas should be deducted from the total. If it is apparent that decided variations

in the reserve stand occur over large areas, these should be treated like a change in type and recorded on the map. The tree data should be recorded by type, site, diameter class, and tree class, separate records being kept for each species. Three groups of tree classes should be recognized: (1) classes 1 and 2; (2) class 3; and (3) the remaining four classes. If the survey is made before the stand is cut, the trees to be cut should be tallied separately.

Site-quality determinations should be made according to the procedure described on page 9, and where one site quality merges into another the different qualities should be blocked out.

The term "reproduction", as used in connection with the field survey, covers the established seedlings below the smallest "pole" size, 3.6 inches at breast height. This portion of the stand approximates an even-aged condition and may be treated as a modified form of an even-aged stand. The easiest way to gather information on the condition of the reproduction is the stocked quadrat system. This system as used in the Pacific Northwest consists in taking a block of four quadrats each 13.2 feet square at definite intervals along the survey line. Each quadrat is 4 milacres, or one two hundred and fiftieth of an acre. The estimator, who may be either the compassman or the tallyman, stops at regular intervals, usually of 1 chain, considers himself at the center of a block of four 13.2-foot squares, looks into one quadrat until he finds an established seedling or sapling, then into the next quadrat, and so on. If each of the four quadrats is occupied by one or more seedlings the block is given a count of 4, if only three are occupied it is given a count of 3, and so forth. When the survey is completed, these tallies are totaled and the number of occupied quadrats is expressed as a percentage of the total number observed; this percentage can then be related directly to any defined stocking classification.

After the survey has been completed in the field, the data should be computed in basal area or in various units of volume as may be desired. After the stand volume is computed, the structure factor is obtained as described on pages 12–13. For use in cases in which neither basal areas nor cubic-foot volumes are computed, but only board-foot volumes, a simple conversion from the structure percentages obtained by board-foot calculations is given in the following tabulation. The exact relationship hinges somewhat upon the average size of the trees, but the values here given will compensate on the average.

| Structure percentage by board-foot volume | Corresponding percentage by basal area or cubic-foot volume |
|---|---|
| 5 | 9 |
| 10 | 15 |
| 15 | 20 |
| 20 | 25 |
| 30 | 34 |
| 40 | 43 |
| 50 | 52 |
| 60 | 61 |
| 70 | 70 |
| 80 | 78 |

### ESTIMATING AVERAGE GROSS YIELDS

In the preparation of the following series of stand-growth charts and tables, the stand was treated as a unit and as many of the factors as possible were disposed of in preliminary calculations not appearing in this bulletin.

Table 6 and figure 8 give the growth in terms of basal area, table 7 and figure 9 in terms of cubic feet, and table 8 and figure 10 in terms of board feet, Scribner rule. In the case of board-foot volume it has been assumed that the upper limit of utilization is a top diameter of 8 inches inside bark and that the lower limit is a breast-height diameter of 11.6 inches. Each table and chart gives the total stand at the end of 10, 20, 30, 40, 50, and 60 years for any reasonable size of reserve. If the reserve stand is of a size not directly given in the tables, it is much easier to use the alinement charts of figures 8, 9, and 10 than to interpolate.

The method of reading the charts is simple. First the number of years after cutting is located on the left-hand scale, then the initial reserve volume is found on the center curved scale. A straight edge spanning these two points and projecting over to the right-hand scale gives the reading for the predicted gross volume. For instance, if the average reserve volume per acre is 2,500 board feet, the reading in figure 10 is 4,700 board feet in 30 years or 6,500 board feet in 60 years.

TABLE 6.—*Basal-area growth in selectively cut stands of ponderosa pine*[1] *of average structure, site quality IV*

| Basal area of reserve stand per acre | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| At time of cutting (square feet) | After an interval of— | | | | | | Average annual increase in basal area per acre for 60-year cycle | |
| | 10 years | 20 years | 30 years | 40 years | 50 years | 60 years | | |
| | *Square feet* | *Square feet* | *Square feet* | *Square feet* | *Square feet* | *Square feet* | *Square feet* | *Per-cent*[2] |
| 5 | 7 | 9 | 11 | 12 | 13 | 14 | 0.15 | 3.00 |
| 10 | 13 | 15 | 18 | 20 | 21 | 22 | .20 | 2.00 |
| 15 | 18 | 21 | 24 | 27 | 28 | 30 | .25 | 1.67 |
| 20 | 24 | 28 | 31 | 34 | 36 | 37 | .28 | 1.40 |
| 25 | 29 | 33 | 37 | 40 | 43 | 44 | .32 | 1.28 |
| 30 | 34 | 39 | 43 | 46 | 49 | 51 | .35 | 1.17 |
| 35 | 39 | 44 | 49 | 52 | 55 | 57 | .37 | 1.06 |
| 40 | 45 | 50 | 55 | 58 | 61 | 63 | .38 | .95 |
| 45 | 49 | 55 | 60 | 63 | 66 | 69 | .40 | .89 |
| 50 | 54 | 60 | 65 | 70 | 72 | 75 | .42 | .84 |
| 55 | 59 | 65 | 70 | 74 | 78 | 80 | .42 | .76 |
| 60 | 64 | 70 | 75 | 80 | 83 | 86 | .43 | .72 |

[1] All trees included.

[2] Simple growth percentage.

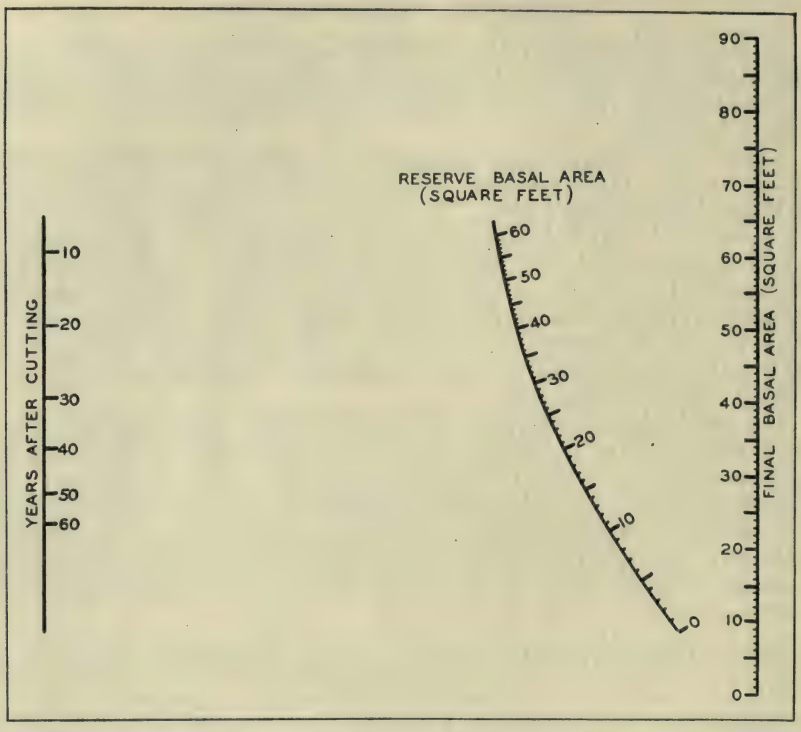



FIGURE 8.—Basal-area growth in selectively cut stands of ponderosa pine in the Pacific Northwest, site quality IV.

TABLE 7.—*Cubic-foot volume growth in selectively cut stands of ponderosa pine* [1] *of average structure, site quality IV*

| At time of cutting (cubic feet) | Volume of reserve stand per acre after an interval of— | | | | | | Average annual increase in volume per acre for 60-year cycle | |
|---|---|---|---|---|---|---|---|---|
| | 10 years | 20 years | 30 years | 40 years | 50 years | 60 years | | |
| | *Cubic feet* | *Cubic feet* | *Cubic feet* | *Cubic feet* | *Cubic feet* | *Cubic feet* | *Cubic feet* | *Percent* [2] |
| 200 | 260 | 330 | 420 | 490 | 550 | 660 | 7.7 | 3.85 |
| 400 | 500 | 600 | 720 | 810 | 900 | 970 | 9.5 | 2.38 |
| 600 | 720 | 840 | 1,000 | 1,110 | 1,210 | 1,300 | 11.7 | 1.95 |
| 800 | 920 | 1,060 | 1,240 | 1,360 | 1,470 | 1,570 | 12.8 | 1.60 |
| 1,000 | 1,150 | 1,320 | 1,500 | 1,640 | 1,770 | 1,890 | 14.8 | 1.48 |
| 1,200 | 1,350 | 1,530 | 1,730 | 1,890 | 2,030 | 2,150 | 15.8 | 1.32 |
| 1,400 | 1,560 | 1,750 | 1,970 | 2,140 | 2,300 | 2,430 | 17.2 | 1.23 |
| 1,600 | 1,780 | 1,980 | 2,200 | 2,390 | 2,540 | 2,700 | 18.3 | 1.14 |
| 1,800 | 1,990 | 2,200 | 2,440 | 2,640 | 2,800 | 2,950 | 19.2 | 1.07 |
| 2,000 | 2,200 | 2,420 | 2,690 | 2,870 | 3,040 | 3,220 | 20.3 | 1.02 |
| 2,200 | 2,410 | 2,650 | 2,920 | 3,120 | 3,310 | 3,490 | 21.5 | .98 |
| 2,400 | 2,630 | 2,880 | 3,170 | 3,400 | 3,570 | 3,750 | 22.5 | .94 |
| 2,600 | 2,870 | 3,120 | 3,410 | 3,650 | 3,850 | 4,020 | 23.7 | .91 |
| 2,800 | 3,080 | 3,350 | 3,650 | 3,900 | 4,100 | 4,300 | 25.0 | .89 |
| 3,000 | 3,320 | 3,600 | 3,910 | 4,150 | 4,370 | 4,610 | 26.8 | .89 |

[1] All trees included.

[2] Simple growth percentage.

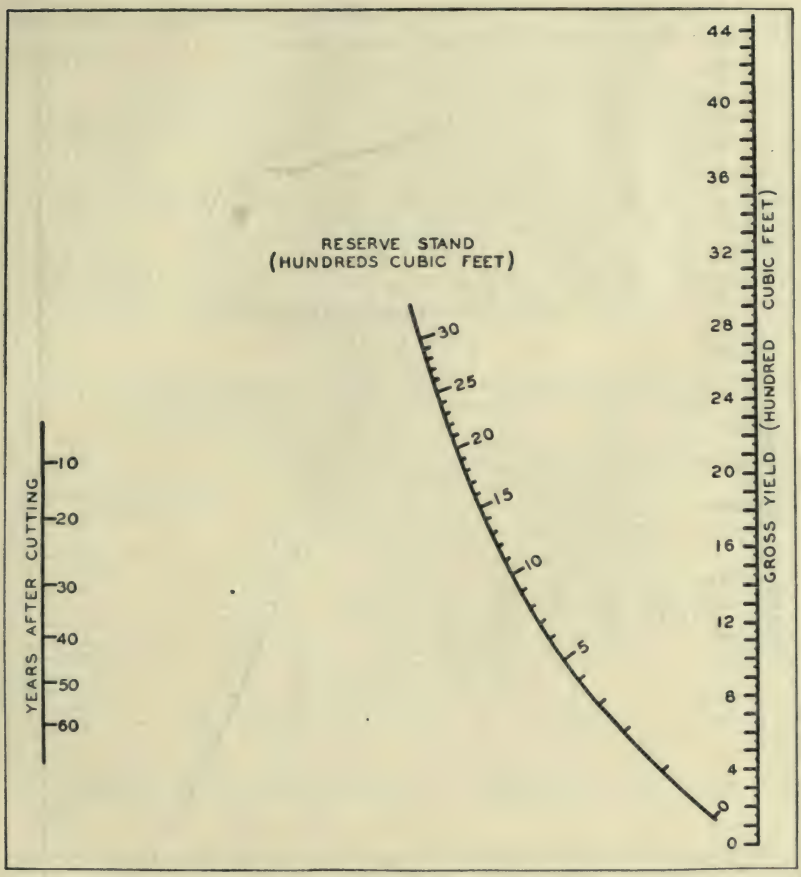



FIGURE 9.—Cubic-foot volume growth in selectively cut stands of ponderosa pine in the Pacific Northwest, site quality IV.

TABLE 8.—*Board-foot volume growth, Scribner rule, in selectively cut stands of ponderosa pine* [1] *of average structure, site quality IV*

| At time of cutting (board feet) | Volume of reserve stand per acre | | | | | | Average annual increase in volume per acre for 60-year cycle | |
|---|---|---|---|---|---|---|---|---|
| | After an interval of— | | | | | | | |
| | 10 years | 20 years | 30 years | 40 years | 50 years | 60 years | | |
| | *Board feet* | *Board feet* | *Board feet* | *Board feet* | *Board feet* | *Board feet* | *Board feet* | *Percent* [2] |
| 1,000 | 1,400 | 1,800 | 2,300 | 2,800 | 3,200 | 3,600 | 43.3 | 4.33 |
| 2,000 | 2,700 | 3,300 | 4,000 | 4,600 | 5,200 | 5,600 | 60.0 | 3.00 |
| 3,000 | 3,900 | 4,500 | 5,400 | 6,100 | 6,700 | 7,300 | 71.7 | 2.39 |
| 4,000 | 4,900 | 5,700 | 6,700 | 7,400 | 8,100 | 8,700 | 78.3 | 1.96 |
| 5,000 | 6,000 | 6,800 | 7,800 | 8,700 | 9,500 | 10,200 | 86.7 | 1.73 |
| 6,000 | 7,000 | 7,900 | 9,000 | 9,900 | 10,800 | 11,500 | 91.7 | 1.53 |
| 7,000 | 8,000 | 9,000 | 10,200 | 11,200 | 12,100 | 13,000 | 100.0 | 1.43 |
| 8,000 | 9,100 | 10,200 | 11,400 | 12,500 | 13,500 | 14,400 | 106.7 | 1.33 |
| 9,000 | 10,200 | 11,300 | 12,700 | 13,800 | 14,900 | 16,000 | 116.7 | 1.30 |
| 10,000 | 11,300 | 12,500 | 14,000 | 15,300 | 16,400 | 17,500 | 125.0 | 1.25 |
| 11,000 | 12,300 | 13,600 | 15,100 | 16,400 | 17,700 | 18,800 | 130.0 | 1.18 |
| 12,000 | 13,300 | 14,700 | 16,300 | 17,800 | 19,200 | 20,300 | 138.3 | 1.15 |
| 13,000 | 14,300 | 15,800 | 17,600 | 19,200 | 20,600 | 21,800 | 146.7 | 1.13 |
| 14,000 | 15,400 | 17,000 | 19,000 | 20,600 | 22,100 | 23,400 | 156.7 | 1.12 |
| 15,000 | 16,500 | 18,300 | 20,300 | 22,100 | 23,700 | 25,100 | 168.3 | 1.12 |
| 16,000 | 17,800 | 19,700 | 21,900 | 23,700 | 25,500 | 27,000 | 183.3 | 1.15 |

[1] All trees 11.6 inches or more in diameter at breast height included.
[2] Simple growth percentage.

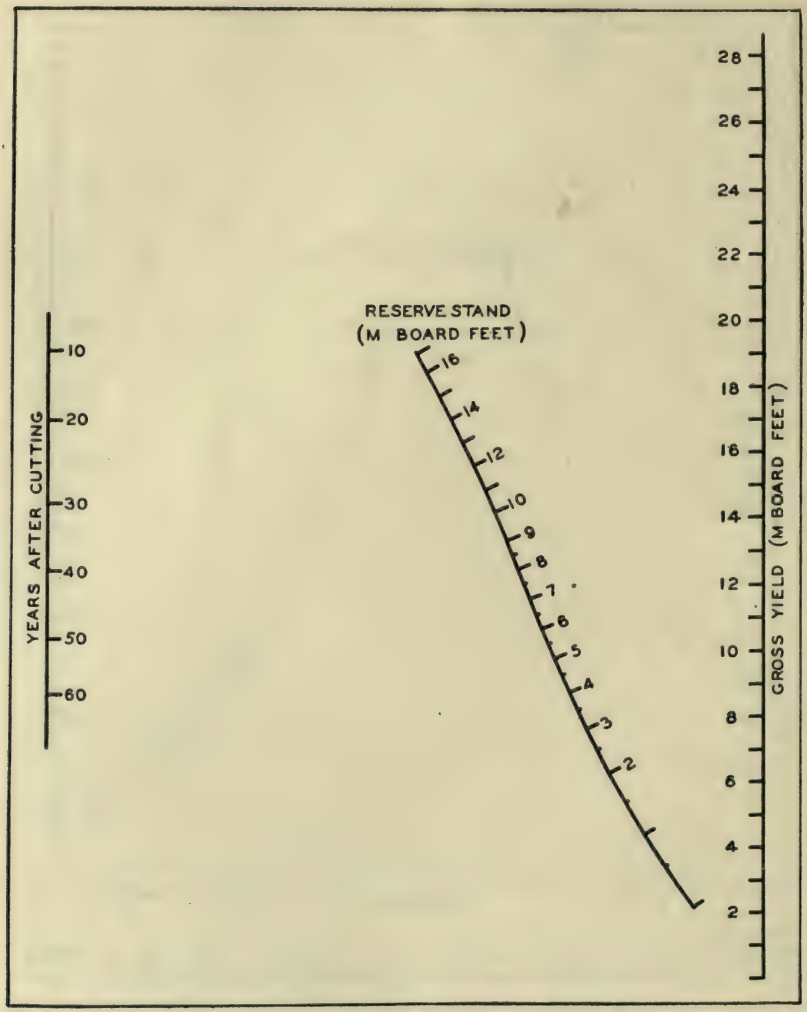



FIGURE 10.—Board-foot volume growth, Scribner rule, in selectively cut stands of ponderosa pine in the Pacific Northwest, site quality IV.

### ADJUSTING FOR SITE QUALITY AND STRUCTURE

The gross yield found by reading from the alinement charts or by interpolation from the tables applies to the average structure and site quality of the entire collection of sample plots. It has been shown previously that stands vary widely in structure and that no average condition is valid for every stand in the entire region. Adjustments must therefore be made for variations in structure and site. Tables 9, 10, and 11, based upon a thorough statistical study of the variations of the growth of plots of different site quality and structure from growth averages, give simple correction percentages by which the preliminary estimated gross yield must be multiplied. For instance if the volume of a reserve stand, on site quality IV, is composed 50 percent of tree classes 1 and 2, and 20 percent of tree class 3, the

preliminary estimated board-foot yield at the end of 60 years is multiplied by 1.11. If, furthermore, the stand were on site quality III instead of IV the correction percentage would be increased by 15, or to 126. For instance, if the 2,500-board-foot stand mentioned in the preceding paragraph, which according to the preliminary estimate will have grown to 6,500 board feet in 60 years, has a 50-20 structure, and if it is on site quality III, the predicted gross volume at 60 years is $6,500 \times 1.26$, or 8,190 board feet. If calculations are made for periods shorter than 60 years, the differences between the correction percentages which tables 9, 10, and 11 give and 100 percent should be correspondingly reduced. If the period is 40 years, for instance, the total correction percentage in the example cited will be 117 instead of 126.

TABLE 9.—*Correction for effect of site quality and structure upon basal area of selectively cut stands of ponderosa pine 60 years after cutting*

| Percentage of basal area in tree class 3 | Correction percentages for site quality IV [1] when the percentage of basal area in tree classes 1 and 2 is— | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 0 | 69 | 76 | 84 | 91 | 99 | 106 | 114 | 121 | 129 | 136 | 144 |
| 10 | 73 | 80 | 88 | 95 | 103 | 110 | 118 | 125 | 133 | 140 | ------ |
| 20 | 77 | 84 | 92 | 99 | 107 | 114 | 122 | 129 | 137 | ------ | ------ |
| 30 | 81 | 88 | 96 | 103 | 111 | 118 | 126 | 133 | ------ | ------ | ------ |
| 40 | 85 | 92 | 100 | 107 | 115 | 122 | 130 | ------ | ------ | ------ | ------ |
| 50 | 89 | 96 | 104 | 111 | 119 | 126 | ------ | ------ | ------ | ------ | ------ |
| 60 | 93 | 100 | 108 | 115 | 123 | ------ | ------ | ------ | ------ | ------ | ------ |
| 70 | 97 | 104 | 112 | 119 | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 80 | 101 | 108 | 116 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 90 | 105 | 112 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 100 | 109 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |

[1] For site quality III, add 8 to the above percentages; for site quality V, subtract 8 from the above percentages.

TABLE 10.—*Correction for effect of site quality and structure upon cubic-foot yield of selectively cut stands of ponderosa pine 60 years after cutting*

| Percentage of basal area in tree class 3 | Correction percentages for site quality IV [1] when the percentage of basal area in tree classes 1 and 2 is— | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 0 | 65 | 73 | 82 | 90 | 98 | 106 | 115 | 123 | 131 | 140 | 148 |
| 10 | 70 | 78 | 87 | 95 | 103 | 111 | 120 | 128 | 136 | 145 | ------ |
| 20 | 75 | 83 | 92 | 100 | 108 | 116 | 125 | 133 | 141 | ------ | ------ |
| 30 | 80 | 88 | 97 | 105 | 113 | 121 | 130 | 138 | ------ | ------ | ------ |
| 40 | 85 | 93 | 102 | 110 | 118 | 126 | 135 | ------ | ------ | ------ | ------ |
| 50 | 90 | 98 | 107 | 115 | 123 | 131 | ------ | ------ | ------ | ------ | ------ |
| 60 | 95 | 103 | 112 | 120 | 128 | ------ | ------ | ------ | ------ | ------ | ------ |
| 70 | 100 | 108 | 117 | 125 | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 80 | 105 | 113 | 122 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 90 | 110 | 118 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 100 | 115 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |

[1] For site quality III, add 12 to the above percentages; for site quality V, subtract 12 from the above percentages.

TABLE 11.—*Correction for effect of site quality and structure upon board-foot yield, by Scribner rule, of selectively cut stands of ponderosa pine 60 years after cutting*

| Percentage of basal area in tree class 3 | Correction percentages for site quality IV [1] when the percentage of basal area in tree classes 1 and 2 is— | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 0 | 62 | 69 | 77 | 85 | 93 | 101 | 108 | 116 | 124 | 132 | 140 |
| 10 | 67 | 75 | 83 | 90 | 98 | 106 | 114 | 122 | 129 | 137 | ------ |
| 20 | 72 | 80 | 88 | 96 | 103 | 111 | 119 | 127 | 135 | ------ | ------ |
| 30 | 78 | 85 | 93 | 101 | 109 | 117 | 124 | 132 | ------ | ------ | ------ |
| 40 | 83 | 91 | 98 | 106 | 114 | 122 | 130 | ------ | ------ | ------ | ------ |
| 50 | 88 | 96 | 104 | 112 | 119 | 127 | ------ | ------ | ------ | ------ | ------ |
| 60 | 93 | 101 | 109 | 117 | 125 | ------ | ------ | ------ | ------ | ------ | ------ |
| 70 | 99 | 107 | 114 | 122 | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 80 | 104 | 112 | 120 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 90 | 109 | 117 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |
| 100 | 115 | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ | ------ |

[1] For site quality III, add 15 to the above percentages; for site quality V, subtract 15 from the above percentages.

### ADJUSTING FOR MORTALITY

Pending the time when average mortality rates over long periods will be definitely determined, a mortality correction of 15 percent of the total gross annual increment has been tentatively adopted for areas where insect infestations can be held to the endemic stage and where wind and drought are not serious considerations. In the example previously cited, if a 2,500-board-foot reserve has given in 60 years a gross yield of 8,190 board feet or a gross increment of 5,690 board feet, the net increment is estimated as $5,690 \times 0.85$, or 4,836 board feet, equivalent to an annual growth of 80.6 board feet.

In cases in which the mortality is extraordinarily high or extraordinarily low the percentage must be adjusted according to the information in a later section (p. 29) which summarizes the best available data on mortality.

The reduction for mortality estimated directly after cutting need not be a final value. There are other ways in which a more accurate value may be obtained. Experience has shown that the greatest mortality occurs within 5 years after the cutting. At the end of that period the areas should be gone over, an estimate of mortality made and applied to the original tally, and new computations of growth made on the basis of the corrected tally.

### ADJUSTING FOR NUMBER OF POLES

One of the main differences between the sample plots upon which this study is based and individual extensive stands to which the results of the study are applied lies in the proportionate number of poles, trees between 3.6 and 11.5 inches in diameter at breast height. In some stands groups of poles are scattered throughout. Where this condition prevails, the growth rates are higher and the prospects of a satisfactory future stand are enhanced. The growth tables take into account the average number of poles, shown in table 12. The number diminishes with heaviness of reserve stand, being 7 for a stand of 1,000 board feet per acre and 2.3 for a stand of 10,000 board feet per acre. Where the number departs widely from the average, an adjustment in the gross estimate is needed.

TABLE 12.—*Average number of trees that grow into the 11.6-inch breast-height diameter class during a 60-year cycle*

| Volume of reserve stand per acre (board feet) | Number of study plots | Number of trees per acre growing into 11.6-inch class | Volume of reserve stand per acre (board feet) | Number of study plots | Number of trees per acre growing into 11.6-inch class |
|---|---|---|---|---|---|
| 0–1,000 | 20 | 7.0 | 5,000–6,000 | 16 | 3.2 |
| 1,000–2,000 | 31 | 5.8 | 6,000–8,000 | 20 | 2.9 |
| 2,000–3,000 | 22 | 5.3 | 8,000–10,000 | 20 | 3.3 |
| 3,000–4,000 | 13 | 4.5 | Over 10,000 | 16 | 2.3 |
| 4,000–5,000 | 19 | 3.7 | | | |

For every extra pole that will enter into the 11.6-inch breast-height diameter, or merchantable-volume, class during a 60-year period the estimate of growth for that period can be increased by from 1 to 4 board feet, according to the initial size and vigor of the pole. If the poles occur in dense groups and were small in size at the time of cutting, the lower value must be taken; if they were large, standing free, and vigorous, a value nearer the larger one is more suitable.

### EXAMPLES OF GROWTH PREDICTIONS

To illustrate the sequence of computations involved in obtaining an estimate of future growth under this plan two sample cases are presented.

#### CASE 1

*Reserve-stand conditions*

| | |
|---|---|
| Site quality | IV. |
| Area | 350 acres. |
| Stand per acre: | |
| Basal area | 30 square feet. |
| Cubic measure | 600 cubic feet. |
| Board measure | 3,000 board feet. |
| Structure | 40–40. |
| Pole condition | Average. |
| Mortality | Do. |
| Length of cutting cycle | 60 years. |

*Computations*

| Item | Basal area | Cubic measure | Board measure |
|---|---|---|---|
| | *Square feet* | *Cubic feet* | *Board feet* |
| Gross yield at 60 years (from tables 6, 7, 8) | 51 | 1,300 | 7,300 |
| | *Percent* | *Percent* | *Percent* |
| Correction for structure (from tables 9, 10, and 11) | 115 | 118 | 114 |
| | *Square feet* | *Cubic feet* | *Board feet* |
| Corrected gross yield | 58.6 | 1,534 | 8,322 |
| Total gross increment | 28.6 | 934 | 5,322 |
| Reduced (15 percent) for mortality | 24.3 | 794 | 4,524 |
| Average net annual growth per acre | .405 | 13.2 | 75.4 |
| No correction necessary for poles. | | | |
| Average net annual growth, entire area | 141.8 | 4,620 | 26,390 |

CASE 2

*Reserve-stand conditions*

| Structure | Site quality | Acres | Reserve |
|---|---|---|---|
| | | | *Board feet* |
| 35–0 | III | 500 | 4,000 |
| 25–50 | IV | 2,000 | 3,500 |
| 25–25 | V | 1,000 | 3,000 |

Cutting cycle, 40 years; mortality, average; pole condition, average.

In this case each type is considered separately and the example breaks down into three separate divisions, for each of which a separate estimate is made in exactly the same manner as in case 1.

*Computations*

| Item | Site quality III | Site quality IV | Site quality V |
|---|---|---|---|
| Gross yield at 40 years (as for site quality IV)—board feet | 7,400 | 6,750.0 | 6,100 |
| Correction for site quality and structure at 40 years—percent | 103 | 105 | 86 |
| Corrected yield—board feet | 7,622 | 7,088 | 5,246 |
| Total gross increment—do | 3,622 | 3,588 | 2,246 |
| Reduced (15 percent) for mortality—do | 3,079 | 3,050 | 1,909 |
| Average net annual growth, per acre—do | 77 | 76.2 | 47.7 |
| Average net annual growth, entire area—do | 38,500 | 152,400 | 47,700 |
| Grand total—do | | 238,600 | |

## ACCURACY OF GROWTH ESTIMATES

No yield prediction is perfect. Every yield table for even-aged stands now prepared is accompanied by a table of errors showing the range about the tabular values through which the yields of the fully stocked stand may vary. In this study of selectively cut stands of ponderosa pine the statistical error was computed by a different and probably more correct method. The volume was definitely determined at the time of cut, and hence had a 0-percent error at 0 age. With advance in age, on many of the plots the volume gradually diverged more and more from the tabular values, becoming in some instances proportionately greater and in others less. These differences were due in part to site quality, to structure, to release conditions, and to changes in plot conditions since the time of cutting. From the percentage differences at each decade a standard error was computed for each decade. Table 13 lists these errors for basal-area, cubic-foot, and board-foot values. The errors listed do not take into account the corrections for site quality and structure given in tables 9 to 11.

TABLE 13.—*Standard errors of yields as estimated for small areas at each decade without correction for site quality and structure*

| Years after cutting | Standard errors around values of tables 6, 7, and 8 | | |
|---|---|---|---|
| | Basal area | Cubic-foot volume | Board-foot volume |
| | *Percent* | *Percent* | *Percent* |
| 10 | 7.2 | 8.0 | 9.0 |
| 20 | 10.9 | 11.7 | 12.2 |
| 30 | 12.9 | 12.9 | 13.1 |
| 40 | 8.0 | 11.6 | 12.7 |
| 50 | 14.5 | 16.9 | 19.9 |
| 60 | 22.3 | 26.0 | 31.9 |

The estimates of error at 40 to 60 years given in table 13 are unreliable, since they are based on a very small number of plots. (See table 2.) By projecting the growth values of younger plots to 40 years and recomputing the errors, the values at this age were revised to 18.6, 19.4, and 20.8 percent, respectively. About 25 percent of the total variation was removed by the application of the correction percentages for site quality and structure. Of the remaining 75 percent of the variation, 17 percent was traced directly to the character of the data, because the age of the cutting was in some cases 60 years, in others around 50 and 40 years, and in still others 30 and 20 years. The serious growth disturbance previously mentioned as occurring on many of the plots during the last 14 years has affected the error calculation at different points, according to the age of the cutting. The final residual 55 to 60 percent of the variation, corresponding to a final standard error at 40 years of $\pm 10$ to $\pm 12$ percent, is due to a large number of minor factors, chiefly local, that cannot be successfully introduced into the growth calculations and that may to some extent be compensative when large areas are surveyed.

In the computations on accuracy of estimate, no erratic data were eliminated. Even known eccentric plots with exceptionally large individual errors of estimate were included. A few examples will show how local variations lead to erratic plot-growth values. Plot 161, in Washington, cut 27 years ago, was located in a river bottom, through which an irrigation ditch was dug a number of years after the cutting. Normally, at 30 years after the cutting the plot would have a volume of only 2,290 board feet per acre; owing to the exceptional moisture conditions, its predicted volume at that time is 2,660 board feet, an overrun of 16 percent. Plot 135, in another part of Washington, cut 24 years ago, which had a heavy advance stand of reproduction at the time of cutting, would normally have had a volume of 3,740 board feet per acre at the 20-year mark; because of the undue competition, its volume at 20 years was only 2,615 board feet, an underrun of 30 percent. Many another instance could be cited in which some extraordinary condition is producing unusual growth. Although these special conditions greatly affect yields on single study plots, on extensive tracts they are undoubtedly largely balanced out. The result is that in contrast with the errors given in table 13 and in the foregoing paragraph, based on the deviations of small areas, on large tracts the errors of growth estimate probably amount only to from 5 to 10 percent.

To forestall any question as to whether this or that factor can be used to decrease the error of estimate, it may be said here that the average size of the tree, the volume of the reserve stand, the structure percentage, and the site quality have no effect beyond those indicated. Greater accuracy in yield predictions can be achieved only by considering minor local factors, as in the two examples just cited.

## MORTALITY

Although the general effect of mortality upon gross yields has already been discussed, because the subject is of so much importance a separate section is here devoted to summarizing some of the mortality information now available that can be applied to conditions in

the Pacific Northwest. Since data on cut-over stands are few, a number of deductions will be made from records taken in uncut stands.

Tallies of trees that died after the cutting were made on all the plots measured for this study. When the total volume of these trees is divided by the number of years since the cutting and again by the number of acres in the plots, the average annual mortality loss per acre is found to be 0.115 square foot basal area, 4.13 cubic feet, or 21.2 board feet. Elimination of nine very erratic plots reduces these values to 0.089 square foot, 1.08 cubic feet, and 15.1 board feet, which can be considered a fair average for the areas studied. At this rate the average gross annual increment of 91 board feet that can be expected over a period of 30 years in the average reserve stand, the volume of which is 4,370 board feet, is reduced by 16.6 percent. This reduction is but slightly in excess of the 15 percent correction in annual increment for mortality recommended here for growth calculations covering long periods.

The Division of Forest Insects, United States Bureau of Entomology, has been carrying on since 1920 in southern Oregon and northern California an interesting series of studies of mortality of ponderosa pine, directed by F. P. Keen, chiefly to determine the damage caused by insects but secondarily to determine damage from other causes. The ponderosa pine forests of southern Oregon and northern California undoubtedly have a greater insect hazard than any other pine forests of the Pacific coast, but they are the only ones in the region for which comprehensive and reliable figures have been obtained. Some of the findings, for example those as to the relative susceptibility of the different tree classes, are applicable to the remainder of the region, although the absolute mortality rates are not. The mortality rates for the 10 years 1921–30 given in table 14 are based upon sample plots, usually of 640 acres each, which are examined annually; they can be considered average for the period in question on a large area of the virgin forests in and near the Rogue River, Fremont, and Modoc National Forests. The rates vary greatly from site to site and from stand to stand. In general, they reached a maximum in 1926 and 1927 and then declined rapidly. The values show plainly that the live volume of most of the stands must have temporarily decreased during the major part of this period, but that if the trend of the last years of the period continues there is promise of a balance, if not of a positive increase.

TABLE 14.—*Annual mortality of ponderosa pine in virgin forests on and near the Rogue River, Fremont, and Modoc National Forests in the period 1921–30* [1]

| Mortality | 1921 | 1922 | 1923 | 1924 | 1925 | 1926 | 1927 | 1928 | 1929 | 1930 |
|---|---|---|---|---|---|---|---|---|---|---|
| Average loss per acre—board feet | 144 | 177 | 142 | 254 | 386 | 477 | 417 | 345 | 333 | 226 |
| Range of loss per acre (section averages)—board feet | 30–317 | 38–396 | 19–430 | 27–600 | 124–860 | 148–985 | 103–1,082 | 116–720 | 58–685 | 69–717 |
| Acreage of plots | 53,080 | 53,080 | 45,080 | 39,960 | 20,920 | 19,640 | 17,400 | 16,120 | 16,760 | 7,000 |

[1] Table based on observations taken by the Division of Forest Insects, U.S. Bureau of Entomology.

Rates of mortality in cut-over stands cannot be deduced from the data upon which table 14 is based even if the values are converted to percentages of the total stand, since the average reserve tree is more resistant than the average tree in the virgin stand. A better idea of the situation in cut-over stands is deducible from table 15, which shows for the same areas the relative susceptibility of the seven tree classes and of subclasses.

TABLE 15.—*Relative susceptibility of ponderosa pine by tree classes to mortality from all causes* [1]

| Tree class | Dominance | Age class (years) | Relative susceptibility [2] | Rank |
|---|---|---|---|---|
| 1 | Dominant | 75− | 0.15 | 1 |
| | do | 75+ | .30 | 2 |
| 2 | Codominant | 75− | .44 | 4 |
| | do | 75+ | .97 | 6 |
| | Intermediate | 75− | 1.69 | 12 |
| | do | 75+ | 2.58 | 16 |
| 3 | Dominant | 150–300 | .39 | 3 |
| 4 | Codominant | 150–300 | 1.11 | 7 |
| | Intermediate | 150–300 | 1.72 | 13 |
| 5 | Dominant | 300+ | .47 | 5 |
| | Codominant | 300+ | 1.22 | 8 |
| | Intermediate | 300+ | 2.38 | 14 |
| 6 | Suppressed | 75− | 2.50 | 15 |
| | do | 75+ | 1.28 | 9 |
| 7 | do | 150–300 | 1.36 | 10 |
| | do | 300+ | 1.45 | 11 |

[1] The chief cause of mortality was action of the western pine beetle (*Dendroctonus brevicomis* Lec.). Table based on observations taken by the Division of Forest Insects, U.S. Bureau of Entomology, in southern Oregon and northern California over 4 years, 1928–31.

[2] A factor of 1 indicates that the tree class forms the same percentage of the dead stand as it does of the live stand.

In table 15 a factor of 1 indicates that the tree class is represented among the dead trees in the same percentage as among the live trees. For instance, if this tree class forms 10 percent of the dead stand by number of trees, it also forms 10 percent of the live stand. The factor of 2 indicates that if the tree class forms 10 percent of the dead stand it forms only 5 percent of the live stand, and so forth. In other words, the higher the factor, the greater the susceptibility indicated, in direct ratio. All the dominant full-crowned trees, whether of class 1, 3, or 5, are well on the safe side, the class 1 trees less than 75 years of age being the best risk. The codominant trees seem to be about an average risk. The intermediate trees, those with the long thin crowns, are evidently the most subject to mortality, the danger being greatest for intermediate trees of classes 2 and 5.

According to the data given in table 15, the practice of leaving dominant trees uncut, with a supplement of codominant trees, should do much toward immunizing a selectively cut stand to insect attack. A reserve stand composed chiefly of dominant trees with scattered codominant trees should suffer only one third to one half the mortality of a reserve stand in which the tree classes are represented in the same proportion as in the virgin stand. On the other hand a stand that is stripped of its best timber, only the smaller intermediate and suppressed trees being left, may suffer up to eight times as much mortality as the wisely cut stand.

## COMPARISON OF RELEASE CONDITIONS IN EXTENSIVE STANDS WITH THOSE ON PLOTS

It is a possible weakness of this study that each sample plot was chosen not as typical of a large surrounding area but simply as exemplifying certain conditions of reserve-stand structure and of site quality, and that measurements were made on the plots only once. A check was needed to determine whether the resulting data express

general conditions. Such a check was made, consisting of 17 random strip surveys of extensive virgin and cut-over areas, for which stand maps similar to those made for the sample plots were constructed. Comparisons were made with the plots as to the spacing of trees, their division into release classes, and the number of poles. The strips included from 4 to 50 acres each, and had a total area of 211 acres. In some of the virgin stands three grades of theoretical markings were made and the effect upon release conditions was observed. Table 16 shows the range of release distances and their average, for trees of different sizes, on the sample plots and on the survey strips.

TABLE 16.—*Release conditions on sample plots and on surveyed strips*

| Average release distance [1] (feet) for trees of size indicated | Plots [2] with— | | Strips [3] with— | |
|---|---|---|---|---|
| | Trees 11.6 inches or more in d.b.h. | Trees 11.5 inches or less in d.b.h. | Trees 11.6 inches or more in d.b.h. | Trees 11.5 inches or less in d.b.h. |
| 6–10 ..... number | 3 | 3 | ---------- | ---------- |
| 11–15 ..... do | 3 | 8 | ---------- | ---------- |
| 16–20 ..... do | 32 | 15 | 2 | 1 |
| 21–25 ..... do | 73 | 34 | 6 | 5 |
| 26–30 ..... do | 45 | 44 | 7 | 4 |
| 31–35 ..... do | 19 | 26 | 2 | 4 |
| 36–40 ..... do | 2 | 15 | ---------- | ---------- |
| 41–45 ..... do | 1 | 7 | ---------- | ---------- |
| 46–50 ..... do | ---------- | 2 | ---------- | ---------- |
| Average release distance,[1] by size groups, of trees on plots and on strips, respectively ..... feet | 24 | 27 | 25 | 28 |
| Average number of trees beyond 50-foot release distance, in percentage of total number ..... percent | 9.5 | 12.1 | 20.3 | 28.9 |

[1] Computed only for trees released within a 50-foot radius.
[2] Plots enumerated as having trees 11.6 inches or more in d.b.h. include 178 of the total 179 study plots. Plots enumerated as having trees below that size include 154 of the total 179.
[3] Strips enumerated as having trees 11.6 inches or more in d.b.h. include all the 17 strips surveyed. Strips enumerated as having trees below that size include 14 of the total 17.

The expression "release distance" as here used signifies the average distance from a reserve tree to a stump more than 12 inches in diameter with no other standing tree intervening. Trees beyond the 50-foot limit are considered unreleased, although release has some effect beyond that distance. Equal average release distances are considered to signify equivalent release conditions. Release conditions and their effect upon growth are dealt with in detail in a later section.

On the sample plots the release distance for the trees included in the board-foot volume calculations (that is, the trees 11.6 inches or more in diameter at breast height), not including trees beyond the 50-foot limit, averaged approximately 24 feet, and that for the smaller trees averaged 27 feet (table 16). Of the total number of trees on the plots, 9.5 percent of those of merchantable size and 12.1 percent of those of unmerchantable size were beyond the 50-foot limit. On the strips, the release distance averaged 25 feet for the larger trees and 28 feet for the smaller trees, and the proportion of the trees beyond the 50-foot limit was 20.3 and 28.9 percent for the two size classes, respectively. The contrast between the two groups of data as to percentage of trees beyond the 50-foot limit, especially in the unmerchantable class, was one reason why in predicting growth

a correction was made for the number of poles that would grow into merchantable size during the cutting cycle. The difference as to percentage of trees outside the 50-foot limit gives a distorted picture, however. From 27 to 53 percent of such trees are free on two or more quadrants before the cutting, many of them being completely isolated and hence having a growth rate far above the average rate in the virgin stand; and many of the others occur in uncut clumps such as were purposely excluded from sample plots because they did not represent a good selection condition.

The average release conditions for extensive stands were first computed for the marking system now used in the Pacific Northwest by the Forest Service, in which 20 to 30 percent of the volume is left as a reserve stand. Then trial markings by one or both of two other systems were made on nine of the strips. One of these systems provided for a reserve of 30 to 40 percent; the second provided for a reserve of 10 percent or less. The heavy reserve contained all trees that could possibly succeed in the selection stand; the light reserve contained all trees with diameters not greater than 18 inches, which, according to certain studies, is the cutting limit that permits maximum present profit without consideration of future benefits.

As is shown in table 17, average release distance for trees within the 50-foot distance is practically independent of grade of cutting. Percentage of trees not released within 50 feet, especially in the small sizes, varies somewhat with grade of cutting; the lighter the reserve, the fewer the unreleased trees. Even in the heavy reserves only one fifth of the merchantable trees are outside effective release distance, a fact that augurs well for improved growth following selective cutting of any grade. Unbroken groups of small trees in the heavy reserves, indicated by the large percentage of trees in this class, should be thinned to improve the growth rates of selected trees and enable a large proportion of them to reach merchantable size.

TABLE 17.—*Release conditions in heavy, medium, and light reserve stands of ponderosa pine on surveyed strips*

| Item | Heavy reserve | Medium reserve | Light reserve |
|---|---|---|---|
| Volume, in percentage of volume before cutting.....percent.. | 30–40 | 20–30 | 0–10 |
| Average release distance: [1] | | | |
| Trees 11.6 inches or more in diameter at breast height.....feet.. | 24 | 25 | 25 |
| Trees 11.5 inches or less in diameter at breast height.....do.... | 29 | 28 | 29 |
| Trees unreleased [2] or free growing: | | | |
| Trees 11.6 inches or more in diameter at breast height.....percent.. | 19 | 29 | 14 |
| Trees 11.5 inches or less in diameter at breast height.....do.... | 37 | 29 | 20 |

[1] Computed only for trees released within a 50-foot radius.
[2] Including all trees not released within a 50-foot radius.

## USE OF STAND-GROWTH TABLES IN CHOOSING GRADE OF CUTTING

The greatest use of the tables presented in this bulletin is in connection with making growth predictions for selectively cut stands. A secondary value lies in the assistance they give in determining what grades of cutting conduce to maximum production. The following tabular statement shows the growth rates obtainable in four different stands under three different grades of cutting. Altogether, tests were made in 17 different stands. The four examples were chosen

because they showed distinct types of selection stands. The effect of grade of cutting on average release conditions has already been discussed, but the suitability of each grade for different stands has not been shown. The removal of all trees 18 inches or more in diameter, for instance, may leave as low as 100 board feet per acre in one stand and as high as 1,750 board feet in another. At the other extreme, cutting to a high diameter limit may leave from 6,000 to 14,000 board feet per acre. Medium to heavy cuttings leave stands ranging from 2,000 to 11,000 board feet per acre, usually in the neighborhood of 4,000 to 5,000 board feet.

*Illustrations of application of growth tables to strip-survey data and the effect of several methods of cutting*

STRIP NO. 7

| | | | |
|---|---|---|---|
| Original stand data: | | | |
| 1. Acres in strip—number | | | 9.0 |
| 2. Average site quality | | | III |
| 3. Volume per acre—board feet | | | 37,003 |
| Structure: | | | |
| 4. Percentage of 1's and 2's | | | .3 |
| 5. Percentage of 3's | | | 31.6 |
| 6. Percentage of 4's, 5's, 6's, and 7's | | | 68.1 |
| Reserve stand data: | *Heavy reserve* | *Medium reserve* | *Light reserve* |
| 7. Volume per acre—board feet | 14,119 | 11,105 | 122 |
| Structure: | | | |
| 8. Percentage of 1's and 2's | .9 | 1.2 | 53.8 |
| 9. Percentage of 3's | 73.7 | 82.5 | |
| 10. Percentage of 4's, 5's, 6's, and 7's | 25.4 | 16.3 | 46.2 |
| 11. Structure and site correction percentage | 117 | 121 | 119 |
| 12. Poles per acre—number | 1.2 | 1.0 | .9 |
| Average release distance: | | | |
| 13. Trees 11.6 inches or more in d.b.h—feet | 31 | 25 | 26 |
| 14. Trees 11.5 inches or less in d.b.h—do | 35 | 36 | 34 |
| Percentage unreleased: | | | |
| 15. Trees 11.6 inches or more in d.b.h—do | 22 | 28 | 0 |
| 16. Trees 11.5 inches or less in d.b.h—do | 46 | 33 | 25 |
| Growth and yield estimates: | | | |
| 17. Gross volume at 60 years as read from chart—board feet | 23,700 | 21,000 | 1,800 |
| 18. Gross volume at 60 years, adjusted—do | 27,730 | 25,410 | 2,140 |
| 19. Gross annual increment—do | 227 | 238 | 33.6 |
| 20. Estimated net annual increment—do | 193 | 202 | 28.6 |
| 21. Estimated net annual increment corrected for poles—board feet | 193 | 202 | 28.6 |

STRIP NO. 10

| | | | |
|---|---|---|---|
| Original stand data: | | | |
| 1. Acres in strip—number | | | 14.5 |
| 2. Average site quality | | | IV |
| 3. Volume per acre—board feet | | | 15,766 |
| Structure: | | | |
| 4. Percentage of 1's and 2's | | | 6.0 |
| 5. Percentage of 3's | | | 27.8 |
| 6. Percentage of 4's, 5's, 6's, and 7's | | | 66.2 |
| Reserve stand data: | *Heavy reserve* | *Medium reserve* | *Light reserve* |
| 7. Volume per acre—board feet | 5,577 | 4,391 | 1,098 |
| Structure: | | | |
| 8. Percentage of 1's and 2's | 14.5 | 16.9 | 46.9 |
| 9. Percentage of 3's | 53.4 | 55.6 | 11.4 |
| 10. Percentage of 4's, 5's, 6's, and 7's | 32.1 | 27.5 | 41.7 |
| 11. Structure and site correction percentage | 101 | 104 | 105 |

*Illustrations of application of growth tables to strip-survey data and the effect of several methods of cutting*—Continued

STRIP NO. 10—Continued

| | Heavy reserve | Medium reserve | Light reserve |
|---|---|---|---|
| Reserve stand data—Continued. | | | |
| 12. Poles per acre—number | 2. 5 | 2. 4 | 2. 5 |
| Average release distance: | | | |
| 13. Trees 11.6 inches or more in d.b.h—feet | 24 | 28 | 26 |
| 14. Trees 11.5 inches or less in d.b.h—do | 32 | 33 | 28 |
| Percentage unreleased: | | | |
| 15. Trees 11.6 inches or more in d.b.h—do | 18 | 23 | 6 |
| 16. Trees 11.5 inches or less in d.b.h—do | 34 | 35 | 12 |
| Growth and yield estimates: | | | |
| 17. Gross volume at 60 years as read from chart—board feet | 11, 000 | 9, 300 | 3, 800 |
| 18. Gross volume at 60 years, adjusted—do | 11, 110 | 9, 670 | 3, 990 |
| 19. Gross annual increment—do | 92 | 88 | 48 |
| 20. Estimated net annual increment—do | 78 | 75 | 40. 8 |
| 21. Estimated net annual increment corrected for poles—board feet | 78 | 75 | 40. 8 |

STRIP NO. 14

| | |
|---|---|
| Original stand data: | |
| 1. Acres in strip—number | 16 |
| 2. Average site quality | IV |
| 3. Volume per acre—board feet | 22, 918 |
| Structure: | |
| 4. Percentage of 1's and 2's | 5. 4 |
| 5. Percentage of 3's | 33. 2 |
| 6. Percentage of 4's, 5's, 6's, and 7's | 61. 4 |

| | Heavy reserve | Medium reserve | Light reserve |
|---|---|---|---|
| Reserve stand data: | | | |
| 7. Volume per acre—board feet | 7, 732 | 4, 877 | 1, 856 |
| Structure: | | | |
| 8. Percentage of 1's and 2's | 15. 5 | 24. 4 | 41. 8 |
| 9. Percentage of 3's | 69. 1 | 64. 4 | 13. 2 |
| 10. Percentage of 4's, 5's, 6's, and 7's | 15. 4 | 11. 2 | 45. 0 |
| 11. Structure and site correction percentage | 111 | 116 | 106 |
| 12. Poles per acre—number | 6. 8 | 6. 4 | 7. 7 |
| Average release distance: | | | |
| 13. Trees 11.6 inches or more in d.b.h—feet | 24 | 27 | 26 |
| 14. Trees 11.5 inches or less in d.b.h—do | 32 | 33 | 27 |
| Percentage unreleased: | | | |
| 15. Trees 11.6 inches or more in d.b.h—do | 18 | 23 | 6 |
| 16. Trees 11.5 inches or less in d.b.h—do | 34 | 35 | 12 |
| Growth and yield estimates: | | | |
| 17. Gross volume at 60 years as read from chart—board feet | 14, 000 | 10, 000 | 5, 400 |
| 18. Gross volume at 60 years, adjusted—do | 15, 540 | 11, 600 | 5, 720 |
| 19. Gross annual increment—do | 130 | 112 | 64. 4 |
| 20. Estimated net annual increment—do | 111 | 95 | 54. 7 |
| 21. Estimated net annual increment corrected for poles—board feet | 119 | 104 | 62. 7 |

STRIP NO. 15

| | |
|---|---|
| Original stand data: | |
| 1. Acres in strip—number | 10 |
| 2. Average site quality | IV |
| 3. Volume per acre—board feet | 16, 976 |
| Structure: | |
| 4. Percentage of 1's and 2's | 4. 1 |
| 5. Percentage of 3's | 20. 6 |
| 6. Percentage of 4's, 5's, 6's, and 7's | 75. 3 |

*Illustrations of application of growth tables to strip-survey data and the effect of several methods of cutting*—Continued

STRIP NO. 15—Continued

| Reserve stand data: | *Heavy reserve* | *Medium reserve* | *Light reserve* |
|---|---|---|---|
| 7. Volume per acre—board feet | 5, 417 | 4, 151 | 1, 501 |
| Structure: | | | |
| 8. Percentage of 1's and 2's | 12. 6 | 16. 4 | 37. 9 |
| 9. Percentage of 3's | 55. 3 | 57. 2 | 7. 8 |
| 10. Percentage of 4's, 5's, 6's, and 7's | 32. 1 | 26. 4 | 54. 3 |
| 11. Structure and site correction percentage | 101 | 105 | 96 |
| 12. Poles per acre—number | 5. 5 | 5. 5 | 5. 7 |
| Average release distance: | | | |
| 13. Trees 11.6 inches or more in d.b.h.—feet | 28 | 31 | 25 |
| 14. Trees 11.5 inches or less in d.b.h.—do | 37 | 37 | 33 |
| Percentage unreleased: | | | |
| 15. Trees 11.6 inches or more in d.b.h.—do | 23 | 26 | 12 |
| 16. Trees 11.5 inches or less in d.b.h.—do | 42 | 42 | 20 |
| Growth and yield estimates: | | | |
| 17. Gross volume at 60 years as read from chart—board feet | 10, 800 | 9, 000 | 4, 700 |
| 18. Gross volume at 60 years, adjusted—do | 10, 910 | 9, 450 | 4, 510 |
| 19. Gross annual increment—do | 92 | 88 | 50. 2 |
| 20. Estimated net annual increment—do | 78 | 75 | 42. 5 |
| 21. Estimated net annual increment corrected for poles—board feet | 82 | 78 | 42. 5 |

On strip 7 the heavy reserve stand gives a smaller annual increment than the medium stand, owing to the fact that the influence of the less desirable trees left restricts the growth rates of the thriftier trees. On the other hand, a light reserve left by the removal of all trees more than 18 inches in diameter is decidedly handicapped as to growth and will probably be a complete failure, especially since poles average only one to the acre, far less than the average.

Annual increment is not always the deciding factor in the choice of grade of marking; quality of timber, quantity of cut, and total stand at time of second cut, also, must be considered. Under certain conditions of market and logging practice a stand of at least 10,000 board feet per acre may be requisite to a second cut. On strip 10 this will be obtained in 60 years by leaving a reserve of 5,000 board feet per acre, between the heavy and medium reserve conditions. So far as annual growth rates alone are concerned, on this strip there is little choice between the heavy and the medium reserve.

Strict application of the 18-inch limit will leave a sufficiently large reserve in only a few stands, of which strip 14 is an example. Here a stand of 1,856 board feet per acre is left, which in 60 years will produce a gross volume of 5,720 board feet.

Medium reserves, of 20 to 30 percent, probably give the largest proportionate yield in the average stand. They have practically the same annual growth rate as the reserves of 30 to 40 percent, although the latter may at times be more desirable because they give larger ultimate volume.

On the whole, if a stand has a moderate proportion of overmature trees a medium reserve of 20 to 30 percent is best. In a stand having the greater part of its volume in thrifty mature trees, a medium to heavy reserve is advisable. Only if a fair proportion of the volume is in advance young growth and the number of poles is well above the average shown in table 12 will a light reserve succeed.

These conclusions are based solely on considerations of growth. Other considerations, economic and silvicultural, will tend to modify them.

## GROWTH OF THE INDIVIDUAL TREE

### DIAMETER GROWTH RATES FOR AVERAGE RELEASE CONDITIONS

Tables 18 to 22, based upon analysis of 3,586 trees, give the essential values from which average diameter growth rates can be found for the

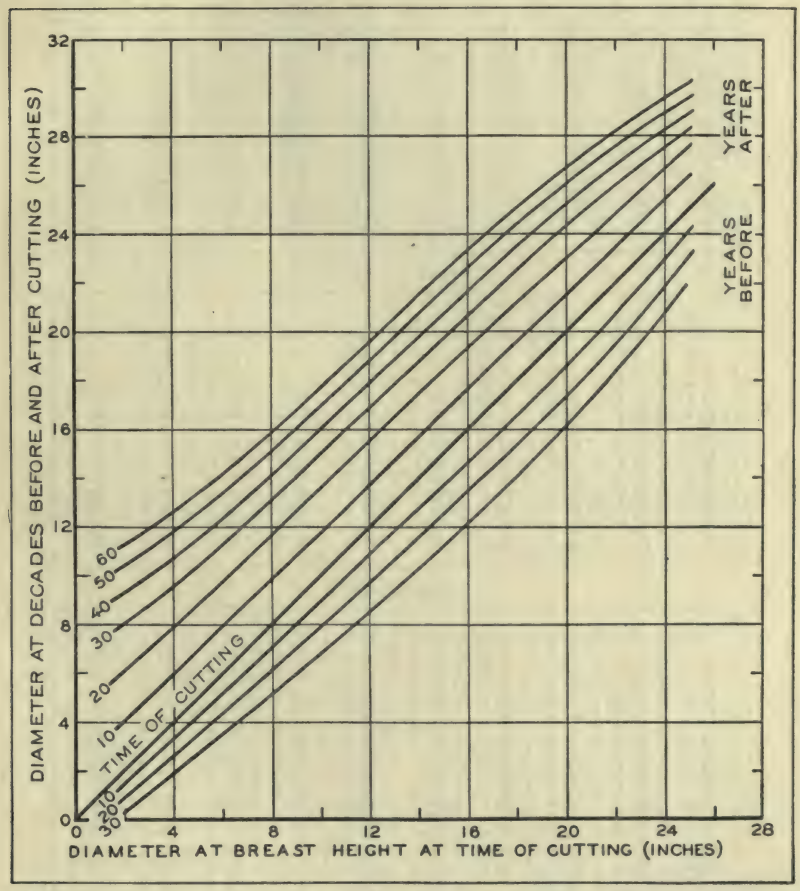



FIGURE 11.—Diameter growth of ponderosa pine, tree class 1, on site quality IV before and after a partial cutting of the stand, by decades.

complete range of diameters in each of the tree classes defined by the Dunning system, as affected by several conditions of release and nonrelease and by different site qualities. Table 18 gives the diameters at 10-year intervals from 30 years before release to 60 years after release for site quality IV. Figure 11 illustrates the method of plotting out the table data for closer interpolation. (Almost any cross-section paper with fine enough divisions can be used for this purpose.) The trees upon analysis of which the tables are based included 479 for site quality III, 2,197 for site quality IV, and 910 for site quality V.

TABLE 18.—*Average diameter growth at breast height, in inches, of ponderosa pine on site quality IV, before and after a partial cutting of the stand*

TREE CLASS 1

| Diameter indicated number of years before release | | | Diameter at time of release | Diameter indicated number of years after release | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 20 | 10 | | 10 | 20 | 30 | 40 | 50 | 60 |
| 0.3 | 0.9 | 1.5 | 2.0 | 4.0 | 6.1 | 8.0 | 9.2 | 10.4 | 11.2 |
| 1.9 | 2.6 | 3.3 | 4.0 | 6.0 | 7.9 | 9.5 | 10.7 | 11.8 | 12.6 |
| 3.5 | 4.4 | 5.2 | 6.0 | 7.9 | 9.8 | 11.2 | 12.3 | 13.4 | 14.1 |
| 5.1 | 6.2 | 7.1 | 8.0 | 9.9 | 11.6 | 13.0 | 14.1 | 15.1 | 15.8 |
| 6.8 | 7.9 | 9.0 | 10.0 | 11.8 | 13.6 | 15.0 | 16.0 | 17.0 | 17.7 |
| 8.5 | 9.7 | 10.9 | 12.0 | 13.7 | 15.5 | 16.9 | 17.9 | 18.8 | 19.6 |
| 10.3 | 11.6 | 12.8 | 14.0 | 15.6 | 17.4 | 18.8 | 19.8 | 20.7 | 21.5 |
| 12.2 | 13.5 | 14.7 | 16.0 | 17.6 | 19.4 | 20.6 | 21.6 | 22.6 | 23.4 |
| 14.1 | 15.4 | 16.6 | 18.0 | 19.6 | 21.2 | 22.5 | 23.4 | 24.4 | 25.1 |
| 16.1 | 17.4 | 18.6 | 20.0 | 21.5 | 23.0 | 24.3 | 25.2 | 26.1 | 26.7 |
| 18.3 | 19.5 | 20.7 | 22.0 | 23.5 | 24.8 | 26.0 | 26.8 | 27.6 | 28.2 |
| 20.7 | 21.8 | 23.0 | 24.0 | 25.4 | 26.6 | 27.5 | 28.2 | 28.9 | 29.5 |
| 23.4 | 24.4 | 25.3 | 26.0 | 27.1 | 28.4 | 29.2 | 29.7 | 30.3 | 30.9 |
| 26.0 | 26.7 | 27.4 | 28.0 | 29.0 | 30.0 | 30.8 | 31.4 | 32.0 | 32.4 |
| 28.3 | 28.8 | 29.4 | 30.0 | 30.8 | 31.9 | 32.7 | 33.3 | 33.8 | 34.3 |
| 30.3 | 30.8 | 31.4 | 32.0 | 32.8 | 33.8 | 34.6 | 35.3 | 35.8 | 36.3 |
| 32.3 | 32.9 | 33.4 | 34.0 | 34.8 | 35.8 | 36.6 | 37.3 | 37.8 | 38.3 |

TREE CLASS 2

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.2 | 0.8 | 1.4 | 2.0 | 3.9 | 5.8 | 7.2 | 8.3 | 9.3 | 10.0 |
| 2.1 | 2.7 | 3.3 | 4.0 | 5.4 | 7.1 | 8.3 | 9.2 | 10.3 | 11.0 |
| 4.0 | 4.6 | 5.3 | 6.0 | 7.2 | 8.6 | 9.8 | 10.7 | 11.7 | 12.4 |
| 5.8 | 6.6 | 7.2 | 8.0 | 9.1 | 10.4 | 11.6 | 12.5 | 13.6 | 14.2 |
| 7.6 | 8.4 | 9.2 | 10.0 | 11.2 | 12.4 | 13.5 | 14.5 | 15.5 | 16.2 |
| 9.5 | 10.4 | 11.2 | 12.0 | 13.2 | 14.4 | 15.4 | 16.4 | 17.3 | 18.0 |
| 11.4 | 12.3 | 13.1 | 14.0 | 15.2 | 16.3 | 17.2 | 18.1 | 18.9 | 19.5 |
| 13.4 | 14.3 | 15.1 | 16.0 | 17.2 | 18.1 | 18.9 | 19.6 | 20.2 | 20.7 |
| 15.8 | 16.5 | 17.2 | 18.0 | 18.8 | 19.6 | 20.4 | 20.9 | 21.4 | 21.9 |
| 18.0 | 18.6 | 19.3 | 20.0 | 20.7 | 21.4 | 22.0 | 22.5 | 23.0 | 23.5 |
| 20.0 | 20.6 | 21.3 | 22.0 | 22.7 | 23.3 | 23.9 | 24.4 | 24.8 | 25.2 |
| 22.0 | 22.6 | 23.3 | 24.0 | 24.7 | 25.3 | 25.9 | 26.4 | 26.8 | 27.2 |
| 24.0 | 24.6 | 25.3 | 26.0 | 26.7 | 27.4 | 27 9 | 28.4 | 28.8 | 29.3 |
| 26.0 | 26.6 | 27.3 | 28.0 | 28.7 | 29.4 | 29.9 | 30.4 | 30.8 | 31.3 |
| 28.0 | 28.6 | 29.3 | 30.0 | 30.7 | 31.4 | 31.9 | 32.4 | 32.9 | 33.3 |

TREE CLASS 3

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5.0 | 5.4 | 5.7 | 6.0 | 7.8 | 10.4 | 12.4 | 14.5 | 16.5 | 18.2 |
| 6.8 | 7.2 | 7.6 | 8.0 | 9.7 | 12.0 | 13.8 | 15.4 | 17.1 | 18.5 |
| 8.3 | 8.8 | 9.4 | 10.0 | 11.6 | 13.6 | 15.2 | 16.6 | 17.9 | 19.1 |
| 9.9 | 10.6 | 11.3 | 12.0 | 13.6 | 15.4 | 16.8 | 17.9 | 18.9 | 20.0 |
| 11.7 | 12.4 | 13.2 | 14.0 | 15.5 | 17.1 | 18.4 | 19.4 | 20.2 | 21.1 |
| 13.8 | 14.5 | 15.3 | 16.0 | 17.4 | 18.9 | 20.1 | 21.0 | 21.8 | 22.5 |
| 15.8 | 16.5 | 17.2 | 18.0 | 19.4 | 20.6 | 21.8 | 22.7 | 23.5 | 24.1 |
| 17.7 | 18.5 | 19.2 | 20.0 | 21.3 | 22.6 | 23.6 | 24.5 | 25.2 | 25.8 |
| 19.7 | 20.4 | 21.2 | 22.0 | 23.2 | 24.4 | 25.4 | 26.3 | 27.0 | 27.6 |
| 21.7 | 22.4 | 23.2 | 24.0 | 25.1 | 26.3 | 27.3 | 28.2 | 29.0 | 29.6 |
| 23.7 | 24.5 | 25.2 | 26.0 | 27.1 | 28.2 | 29.2 | 30.1 | 30.9 | 31.5 |
| 25.7 | 26.5 | 27.3 | 28.0 | 29.0 | 30.0 | 31.0 | 32.0 | 32.8 | 33.4 |
| 27.8 | 28.5 | 29.3 | 30.0 | 30.9 | 31.8 | 32.9 | 33.8 | 34.6 | 35.1 |
| 30.1 | 30.7 | 31.4 | 32.0 | 32.8 | 33.7 | 34.6 | 35.5 | 36.1 | 36.6 |
| 32.5 | 33.0 | 33.5 | 34.0 | 34.6 | 35.5 | 36.1 | 36.9 | 37.5 | 38.0 |
| 34.8 | 35.2 | 35.6 | 36.0 | 36.6 | 37.3 | 37.9 | 38.5 | 39.1 | 39.6 |
| 36.8 | 37.2 | 37.6 | 38.0 | 38.6 | 39.1 | 39.7 | 40.3 | 40.9 | 41.4 |
| 38.8 | 39.2 | 39.6 | 40.0 | 40.6 | 41.1 | 41.7 | 42.3 | 42.8 | 43.3 |

TREE CLASS 4

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 4.3 | 4.8 | 5.4 | 6.0 | 8.5 | 11.0 | 12.4 | 13.6 | 14.8 | 15.5 |
| 6.3 | 6.8 | 7.4 | 8.0 | 9.8 | 11.7 | 13.0 | 14.2 | 15.3 | 16.0 |
| 8.3 | 8.8 | 9.4 | 10.0 | 11.3 | 12.8 | 14.0 | 15.1 | 16.1 | 16.7 |
| 10.3 | 10.8 | 11.4 | 12.0 | 12.9 | 14.2 | 15.2 | 16.2 | 17.3 | 17.8 |
| 12.3 | 12.8 | 13.5 | 14.0 | 14.8 | 15.9 | 16.8 | 17.7 | 18.6 | 19.1 |
| 14.3 | 14.9 | 15.5 | 16.0 | 16.8 | 17.8 | 18.7 | 19.5 | 20.3 | 20.8 |
| 16.3 | 16.9 | 17.5 | 18.0 | 18.8 | 19.8 | 20.7 | 21.4 | 22.2 | 22.7 |
| 18.3 | 18.9 | 19.5 | 20.0 | 20.8 | 21.8 | 22.6 | 23.4 | 24.2 | 24.7 |
| 20.3 | 20.9 | 21.5 | 22.0 | 22.8 | 23.7 | 24.5 | 25.3 | 26.1 | 26.6 |
| 22.3 | 22.9 | 23.5 | 24.0 | 24.7 | 25.6 | 26.5 | 27.3 | 27.9 | 28.4 |
| 24.4 | 25.0 | 25.6 | 26.0 | 26.7 | 27.5 | 28.2 | 28.9 | 29.5 | 30.0 |
| 26.5 | 27.1 | 27.6 | 28.0 | 28.6 | 29.2 | 29.8 | 30.3 | 30.8 | 31.3 |
| 28.6 | 29.2 | 29.6 | 30.0 | 30.5 | 30.9 | 31.4 | 31.9 | 32.3 | 32.8 |
| 30.8 | 31.2 | 31.6 | 32.0 | 32.4 | 32.8 | 33.2 | 33.6 | 34.1 | 34.5 |
| 32.8 | 33.2 | 33.6 | 34.0 | 34.4 | 34.8 | 35.2 | 35.5 | 35.9 | 36.4 |

TABLE 18.—*Average diameter growth at breast height, in inches, of ponderosa pine on site quality IV, before and after a partial cutting of the stand*—Continued

TREE CLASS 5

| Diameter indicated number of years before release | | | Diameter at time of release | Diameter indicated number of years after release | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 30 | 20 | 10 | | 10 | 20 | 30 | 40 | 50 | 60 |
| 12.6 | 13.1 | 13.5 | 14.0 | 14.9 | 16.3 | 17.4 | 18.3 | 18.9 | 19.5 |
| 14.6 | 15.1 | 15.5 | 16.0 | 16.8 | 17.8 | 18.7 | 19.4 | 20.0 | 20.6 |
| 16.6 | 17.1 | 17.5 | 18.0 | 18.7 | 19.6 | 20.2 | 20.8 | 21.4 | 22.0 |
| 18.6 | 19.1 | 19.5 | 20.0 | 20.5 | 21.4 | 22.0 | 22.6 | 23.1 | 23.7 |
| 20.6 | 21.1 | 21.5 | 22.0 | 22.6 | 23.4 | 24.0 | 24.6 | 25.1 | 25.6 |
| 22.5 | 23.1 | 23.5 | 24.0 | 24.6 | 25.3 | 26.0 | 26.6 | 27.1 | 27.6 |
| 24.5 | 25.1 | 25.5 | 26.0 | 26.6 | 27.3 | 27.9 | 28.5 | 29.1 | 29.6 |
| 26.5 | 27.0 | 27.5 | 28.0 | 28.6 | 29.2 | 29.8 | 30.4 | 31.0 | 31.5 |
| 28.5 | 29.0 | 29.5 | 30.0 | 30.6 | 31.2 | 31.8 | 32.4 | 33.0 | 33.4 |
| 30.5 | 31.0 | 31.5 | 32.0 | 32.6 | 33.2 | 33.8 | 34.3 | 34.9 | 35.4 |
| 32.5 | 33.0 | 33.5 | 34.0 | 34.5 | 35.1 | 35.7 | 36.2 | 36.8 | 37.4 |
| 34.5 | 35.0 | 35.5 | 36.0 | 36.5 | 37.1 | 37.6 | 38.2 | 38.8 | 39.3 |
| 36.5 | 37.0 | 37.5 | 38.0 | 38.5 | 39.0 | 39.6 | 40.1 | 40.7 | 41.2 |
| 38.4 | 39.0 | 39.5 | 40.0 | 40.5 | 41.0 | 41.6 | 42.1 | 42.7 | 43.2 |
| 40.4 | 41.0 | 41.6 | 42.0 | 42.5 | 43.0 | 43.5 | 44.0 | 44.6 | 45.1 |
| 42.4 | 43.0 | 43.6 | 44.0 | 44.5 | 45.0 | 45.5 | 46.0 | 46.6 | 47.1 |
| 44.4 | 45.0 | 45.6 | 46.0 | 46.5 | 47.0 | 47.5 | 48.0 | 48.6 | 49.1 |
| 46.5 | 47.1 | 47.6 | 48.0 | 48.5 | 49.0 | 49.5 | 50.0 | 50.6 | 51.1 |

TREE CLASS 6

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.9 | 1.4 | 1.8 | 2.0 | 3.1 | 4.5 | 5.7 | 6.6 | 7.5 | 8.3 |
| 2.7 | 3.2 | 3.6 | 4.0 | 4.9 | 6.0 | 7.1 | 8.0 | 8.9 | 9.7 |
| 4.5 | 5.0 | 5.5 | 6.0 | 6.8 | 7.7 | 8.7 | 9.6 | 10.5 | 11.2 |
| 6.4 | 7.0 | 7.5 | 8.0 | 8.8 | 9.7 | 10.6 | 11.5 | 12.2 | 12.9 |
| 8.4 | 9.0 | 9.5 | 10.0 | 10.8 | 11.6 | 12.6 | 13.4 | 14.1 | 14.8 |
| 10.4 | 11.0 | 11.5 | 12.0 | 12.8 | 13.6 | 14.5 | 15.3 | 16.0 | 16.6 |
| 12.4 | 13.0 | 13.5 | 14.0 | 14.7 | 15.6 | 16.4 | 17.2 | 17.9 | 18.5 |
| 14.5 | 15.0 | 15.5 | 16.0 | 16.7 | 17.5 | 18.4 | 19.1 | 19.8 | 20.4 |
| 16.6 | 17.1 | 17.6 | 18.0 | 18.7 | 19.5 | 20.3 | 21.0 | 21.7 | 22.3 |

TREE CLASS 7

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0.8 | 1.2 | 1.6 | 2.0 | 3.8 | 5.2 | 6.4 | 7.2 | 7.8 | 8.4 |
| 2.8 | 3.2 | 3.6 | 4.0 | 5.2 | 6.4 | 7.5 | 8.2 | 8.9 | 9.5 |
| 4.8 | 5.2 | 5.6 | 6.0 | 6.9 | 7.9 | 8.8 | 9.6 | 10.3 | 10.9 |
| 6.8 | 7.2 | 7.6 | 8.0 | 8.6 | 9.5 | 10.5 | 11.2 | 11.8 | 12.4 |
| 8.7 | 9.2 | 9.6 | 10.0 | 10.6 | 11.4 | 12.2 | 12.9 | 13.5 | 14.1 |
| 10.7 | 11.2 | 11.6 | 12.0 | 12.6 | 13.4 | 14.2 | 14.9 | 15.4 | 16.0 |
| 12.7 | 13.2 | 13.6 | 14.0 | 14.6 | 15.4 | 16.2 | 16.8 | 17.4 | 17.9 |
| 14.6 | 15.1 | 15.6 | 16.0 | 16.6 | 17.3 | 18.1 | 18.8 | 19.4 | 19.9 |
| 16.6 | 17.1 | 17.6 | 18.0 | 18.6 | 19.3 | 20.1 | 20.7 | 21.3 | 21.9 |
| 18.6 | 19.1 | 19.6 | 20.0 | 20.6 | 21.3 | 22.0 | 22.7 | 23.3 | 23.8 |
| 20.6 | 21.1 | 21.6 | 22.0 | 22.6 | 23.3 | 24.0 | 24.6 | 25.2 | 25.8 |
| 22.6 | 23.1 | 23.6 | 24.0 | 24.6 | 25.2 | 25.9 | 26.6 | 27.2 | 27.7 |

The growth data given in table 18 for the 30 years before release are applicable to trees in virgin stands or to other unreleased trees. They can be applied to the present diameter tallies of uncut forests in order to estimate the future sizes of the trees. Then the gross increment can be computed by the use of volume tables on the two tallies.

The term "after release" as used in the table is not strictly accurate; the values given under this heading represent the average condition for the whole of a reserve stand that constitutes in some instances as high as 40 or 50 percent of the original stand by volume and in which not all the trees have been released.

Table 18 is in terms of total diameter; to determine the differences in growth rate due to differences in tree class, spacing, release, and

site quality as shown in tables 19 to 22, only the diameter increment was taken. This procedure eliminated the size of the tree as a variable, with the result that small differences were more easily discernible. The percentage relationships given in tables 19 to 22 should therefore be applied solely to diameter increment; to apply them to total diameter would lead to gross error.

TABLE 19.—*Rank of tree classes as to diameter growth before and after selection cutting, and acceleration in diameter growth by tree classes after the cutting, for ponderosa pine on site quality IV*

| Tree class | Average diameter growth for 20 years previous to release | | | Average diameter growth for 20 years after release | | | Acceleration for 20 years' growth |
|---|---|---|---|---|---|---|---|
| | Rank | Absolute growth | Relation to fastest | Rank | Absolute growth | Relation to fastest | |
| | | *Inches* | *Percent* | | *Inches* | *Percent* | *Percent* |
| 1 | 1 | 2.10 | 100 | 1 | 3.54 | 100 | 69 |
| 2 | 2 | 1.48 | 70 | 3 | 2.48 | 70 | 68 |
| 3 | 2 | 1.48 | 70 | 2 | 2.70 | 76 | 82 |
| 4 | 3 | 1.18 | 56 | 4 | 1.92 | 54 | 63 |
| 5 | 4 | .98 | 47 | 7 | 1.29 | 36 | 32 |
| 6 | 5 | .92 | 44 | 5 | 1.73 | 49 | 88 |
| 7 | 6 | .84 | 40 | 6 | 1.45 | 41 | 73 |

Table 19 throws a number of interesting sidelights on the diameter-growth table preceding it, by ranking the tree classes as to diameter growth. In respect to growth rate before release, tree class 1 stands first and is followed by the other classes in this order: 2 and 3, 4, 5, 6, 7. After release the order is as follows: 1, 3, 2, 4, 6, 7, 5.

Information as to the degree to which the average growth rate of a tree class increases after a selection cutting is often interesting, although of no practical use. In this study, for the 20-year period after cutting the tree classes 1 to 7 on the average show the following acceleration percentages, respectively: 69, 68, 82, 63, 32, 88, and 73. Classes 3 and 6 show the greatest average acceleration, and class 5 the least. An anomaly exists here in that some of the tree classes showing only a medium percentage acceleration, like class 1, do so because in the uncut forest they had a much larger absolute growth rate than other classes.

### CORRELATION OF SITE QUALITY, RELEASE DISTANCE, AND NUMBER OF SIDES RELEASED WITH DIAMETER GROWTH

An intensive study of the variations in diameter growth involves tree class, site quality, spacing, release distance, number of sides released, and number of years after cutting. To simplify the calculations and the explanation only one interval after cutting, 20 years, and often only two tree classes, 1 and 3, were taken. In the following discussion and tables, the actual diameter increment for the 20 years after release is compared with the actual diameter increment for the 20 years before release; in addition the actual increments are compared with the increments for site quality IV as read from table 18. This double comparison shows the differences due to the several factors studied.

In defining release conditions not every minute variation could be observed, since application of the results would depend not upon

detail but upon broad conditions. The following binumeral factor was adopted as giving the best working basis: Release factor = distance to nearest stump, number of quadrants released within 50 feet.

The distance to the nearest stump 12 inches or more in diameter was expressed in 5-foot belts, up to a maximum of 50 feet. As "nearest" stump was taken the nearest between which and the tree in question no other tree intervened. The number of quadrants was expressed directly. For instance, a release factor of 6, 2 meant that the nearest stump 12 inches or more in diameter was located 25 to 30 feet away and that within 50 feet stumps were located in two quadrants. Two stumps in one quadrant counted no more than a single stump. Plot upon plot and stand after stand were examined in this fashion in order to evaluate release conditions. Tables 20, 21, and 22 give the substance of the data on effects of various release conditions, comparing actual values with estimated values based on averages given in table 18.

Table 20, which gives diameter increment for the 20 years before and the 20 years after release for the two fastest growing tree classes, 1 and 3, shows that retardation of growth before release and acceleration of growth after release were progressively greater according to the number of sides released. A tree with only 1 side released, for example, often had had no near neighbors except on 1 or 2 sides and had grown faster before release than trees growing in more crowded conditions, and for this reason its growth rate was less susceptible of improvement through release.

TABLE 20.—*Diameter growth of ponderosa pine in selectively cut stands on site quality IV, by number of sides released*

| Tree class | Trees examined | Sides released | Actual average 20-year diameter increment | | Actual diameter-growth acceleration following release | Estimated 20-year diameter increment | | Differences between actual and estimated 20-year diameter growth | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Before release | After release | | Before release | After release | Before release | | After release | |
| | *Number* | *Number* | *Inches* | *Inches* | *Percent* | *Inches* | *Inches* | *Inches* | *Percent* | *Inches* | *Percent* |
| 1 | 251 | 1 | 2.26 | 3.34 | 48 | 2.12 | 3.51 | +0.14 | +6.6 | −0.17 | −4.8 |
| | 122 | 2 | 2.14 | 3.45 | 61 | 2.19 | 3.50 | −.05 | −2.3 | −.05 | −1.4 |
| | 61 | 3 | 1.71 | 3.72 | 118 | 2.19 | 3.47 | −.48 | −21.9 | +.25 | +7.2 |
| | 13 | 4 | 1.52 | 4.09 | 169 | 2.25 | 3.50 | −.73 | −32.4 | +.59 | +16.9 |
| 3 | 258 | 1 | 1.71 | 2.34 | 37 | 1.43 | 2.53 | +.28 | +19.6 | −.19 | −7.5 |
| | 208 | 2 | 1.51 | 2.61 | 73 | 1.49 | 2.73 | +.02 | +1.3 | −.12 | −4.4 |
| | 153 | 3 | 1.34 | 3.10 | 131 | 1.48 | 2.85 | −.14 | −9.5 | +.25 | +8.8 |
| | 31 | 4 | 1.39 | 2.97 | 114 | 1.48 | 2.79 | −.09 | −6.1 | +.18 | +6.5 |

According to the data presented in table 20, the rates of increment after release for single trees of classes 1 and 3 depart from the average rates given for those classes in table 18 in proportions varying from −5 to +17 percent for tree class 1 and from −8 to +9 percent for tree class 3, the variation in growth corresponding closely with variation in number of sides released. The number of cases in which trees are released on three or more sides forms only one sixth to one quarter of the total number of trees released within 50 feet. (It should be noted that the percentage differences stated apply to increment alone, not to total diameters.)

Tree class 1, which has been shown in table 19 to increase its growth after release on the average by 69 percent, is shown by table 20 to

increase it by 48, 61, 118, or 169 percent according as release takes place on 1, 2, 3, or 4 sides, respectively. Tree class 3, which increases its growth after release by an average of about 82 percent, increases it by 37, 73, 131, or 114 percent accordingly as release takes place on 1, 2, 3, or 4 sides, respectively. In both instances, the difference between actual and estimated diameter increment is smallest for the trees released on two sides. Consequently, the improvement that follows release on two sides approximately corresponds to average improvement.

The effect of release varies not only with number of sides released but also with distance of release, or distance to the nearest stump. Table 21 shows just how far the actual growth rates corresponding with different release distances exceed or fall short of the estimated rates. The table contains a number of irregularities, since the values are uncurved and no erratic material has been eliminated. Even in as large a number of trees as that used in this study, each of 126 subdivisions is necessarily small. The principal deductions can be briefly stated as follows:

Release distance depends to a large degree upon spacing in the virgin stand. For the most part, the growth rates in uncut stands increase regularly from a narrow to a wide spacing or, in terms of the headings of table 21, from what will be short release distances after cutting to what will be long release distances.

Since the estimated growth values of table 21 are for site quality IV, the differences in increment due to site quality are the direct differences in the average values from 100. In virgin stands, diameter increments for all tree classes and release distances combined are 21 percent better on site quality III than on site quality IV and those on V are only about 6 percent poorer than those on IV. After release, the growth on site quality III is 37 percent better, and that on V is 9 percent poorer, than that on site quality IV previous to release. (Again, these percentages apply solely to the increment and not to the diameters.)

On site quality V, the average growth rates of the young tree classes 1, 2, and 6 and of the overmature class 5 of the selected data are within 6 percent of those on site quality IV in both uncut and selectively cut stands. On site quality III, the growth rates of tree classes 6 and 7 before release are the only ones within 5 percent of those on site quality IV, all other classes growing much faster than on site quality IV.

On site quality III, the growth rates after release for all tree classes are 136 to 143 percent, averaging roughly 140 percent, of the rates estimated for site quality IV for trees released to distances as great as 40 feet. Beyond this distance the rates are 124 to 127 percent, averaging roughly 125 percent, of those estimated for site quality IV. On site quality IV, up to 40 feet release distance, the average growth rate after release for all tree classes combined closely approximates the estimated average rate. For greater distances the rate falls off somewhat. On site quality V, the decrease of actual growth as compared with estimated growth after release begins in the 31–40-foot release class instead of beyond 40 feet as on the other two sites.

TABLE 21.—*Actual diameter growth of ponderosa pine in selectively cut stands as compared with estimated growth for site quality IV, by site quality, tree class, and release distance*

| Site quality | Tree class | Number of trees examined | Ratio percent of actual growth in 20 years preceding release to estimated growth in 20 years preceding release, by release distance— | | | | | | | Ratio percent of actual growth in 20 years following release to estimated growth in 20 years following release, by release distance— | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1–10 feet | 11–20 feet | 21–30 feet | 31–40 feet | 41–50 feet | Over 50 feet | Average | 1–10 feet | 11–20 feet | 21–30 feet | 31–40 feet | 41–50 feet | Over 50 feet | Average |
| III | 1 | 96 | 109 | 104 | 117 | 112 | 126 | 121 | 113 | 118 | 147 | 151 | 126 | 124 | 125 | 133 |
| | 2 | 48 | 143 | 120 | 115 | 109 | 144 | 162 | 131 | 190 | 187 | 126 | 129 | 129 | 130 | 146 |
| | 3 | 163 | 118 | 128 | 123 | 147 | 147 | 176 | 132 | 143 | 127 | 131 | 166 | 114 | 140 | 138 |
| | 4 | 80 | 97 | 101 | 131 | 114 | 142 | 208 | 114 | 147 | 149 | 153 | 149 | 175 | 146 | 151 |
| | 5 | 36 | 74 | 118 | 89 | 117 | 142 | 157 | 115 | 95 | 188 | 149 | 178 | 152 | 153 | 142 |
| | 6 | 20 | 90 | 86 | 89 | 106 | 112 | 130 | 101 | 94 | 148 | 158 | 139 | 110 | 23 | 124 |
| | 7 | 36 | 97 | 88 | 93 | 132 | 106 | 85 | 99 | 106 | 166 | 105 | 90 | 89 | 95 | 110 |
| Average | | | 106 | 113 | 119 | 123 | 133 | 150 | 121 | 136 | 143 | 138 | 142 | 124 | 127 | 137 |
| IV | 1 | 494 | 71 | 92 | 94 | 92 | 118 | 115 | 100 | 95 | 97 | 99 | 98 | 93 | 88 | 95 |
| | 2 | 192 | 70 | 86 | 105 | 127 | 114 | 119 | 104 | 87 | 99 | 100 | 108 | 101 | 91 | 98 |
| | 3 | 666 | 85 | 94 | 108 | 119 | 130 | 139 | 105 | 94 | 99 | 97 | 109 | 93 | 87 | 98 |
| | 4 | 456 | 76 | 89 | 99 | 113 | 117 | 125 | 93 | 103 | 101 | 107 | 112 | 86 | 91 | 102 |
| | 5 | 106 | 124 | 99 | 95 | 104 | 90 | 103 | 102 | 112 | 109 | 97 | 89 | 84 | 88 | 101 |
| | 6 | 88 | 90 | 91 | 108 | 82 | 121 | 116 | 101 | 114 | 110 | 99 | 81 | 96 | 81 | 98 |
| | 7 | 188 | 71 | 76 | 98 | 102 | 117 | 134 | 87 | 101 | 97 | 103 | 97 | 116 | 88 | 100 |
| Average | | | 79 | 91 | 101 | 107 | 119 | 121 | 100 | 98 | 99 | 100 | 103 | 93 | 88 | 98 |
| V | 1 | 267 | 71 | 90 | 91 | 106 | 120 | 121 | 99 | 94 | 98 | 95 | 83 | 103 | 95 | 94 |
| | 2 | 141 | 70 | 100 | 80 | 131 | 114 | 131 | 95 | 105 | 107 | 86 | 88 | 94 | 77 | 95 |
| | 3 | 172 | 85 | 88 | 93 | 96 | 90 | 127 | 91 | 85 | 76 | 82 | 69 | 68 | 85 | 79 |
| | 4 | 138 | 68 | 75 | 85 | 86 | 101 | 125 | 78 | 86 | 91 | 88 | 107 | 69 | 56 | 87 |
| | 5 | 34 | 48 | 110 | 95 | 102 | 103 | 122 | 101 | 79 | 90 | 138 | 106 | 72 | 158 | 97 |
| | 6 | 85 | 74 | 65 | 108 | 125 | 96 | 130 | 99 | 110 | 92 | 93 | 92 | 54 | 80 | 96 |
| | 7 | 65 | 79 | 58 | 68 | 60 | 76 | 125 | 69 | 95 | 105 | 92 | 69 | 87 | 64 | 94 |
| Average | | | 74 | 86 | 90 | 108 | 110 | 123 | 94 | 94 | 92 | 95 | 85 | 89 | 88 | 91 |

## CORRELATION OF CROWN LENGTH WITH DIAMETER GROWTH

Crown length is another of the factors used in Dunning's tree classification. In practical classification of border-line cases, the exact definition of crown length is often dropped in favor of the general vigor and age of the tree. It is interesting therefore to know how crown length is correlated with diameter growth. Table 22 gives the necessary data on tree classes 1 and 3.

TABLE 22.—*Correlation of crown length with diameter growth in ponderosa pine before and after release*

| Ratio of crown length to total height (percent) | Tree class 1 | | | | | Tree class 3 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Trees examined | Diameter growth in 20 years— | | | | Trees examined | Diameter growth in 20 years— | | | |
| | | Preceding release | | Following release | | | Preceding release | | Following release | |
| | *Number* | *Inches* | *Percent of estimated value* [1] | *Inches* | *Percent of estimated value* [1] | *Number* | *Inches* | *Percent of estimated value* [1] | *Inches* | *Percent of estimated value* [1] |
| 95 | 50 | 2.84 | 123 | 3.60 | 102 | 10 | 1.90 | 127 | 2.99 | 123 |
| 85 | 235 | 2.14 | 103 | 3.52 | 101 | 169 | 2.00 | 135 | 3.08 | 110 |
| 75 | 90 | 2.01 | 94 | 3.19 | 90 | 114 | 1.44 | 97 | 2.65 | 98 |
| 65 | 106 | 2.16 | 97 | 3.17 | 91 | 288 | 1.51 | 101 | 2.58 | 88 |
| 55 | 9 | 1.36 | 63 | 2.49 | 71 | 28 | 1.55 | 103 | 1.85 | 76 |
| 45 or less | 4 | 1.18 | 52 | 2.70 | 79 | 24 | 1.45 | 97 | 2.00 | 79 |

[1] Estimated values shown in table 18.

The sharpest change, with tree class 1, comes between 65 and 55 percent in both virgin and cut stands. For tree class 3 the best growth in virgin stands is that of trees with 85- and 95-percent crown lengths; in cut stands there is a steady decrease in growth rate with shortening of the crown, with a decided diminution when 65-percent crown length is reached. The desirability of avoiding cutting trees having crown lengths of more than 65 percent is therefore indicated by these data.

### HEIGHT GROWTH IN SELECTIVELY CUT STANDS

Basal-area increment and height increment together determine volume growth. Height growth can be taken into consideration in estimating volume growth of uncut stands by using a diameter-height curve. If the same height curve is used for earlier and later ages, the calculations of increase in diameter over a period of years will be accompanied by a calculation of height increment that will approximate the truth. In cut-over stands, acceleration of diameter growth is not accompanied by an acceleration of height growth similar to that which takes place in uncut stands. The final average effect is a dropping of the height curve throughout its length by 5 to 10 feet.

For single trees the approximate age and growth rate of which are known, table 23 gives the relationships between height and diameter growth as accurately as these can be determined by analyzing felled sample trees in cut-over stands.

TABLE 23.—*Height growth in selectively cut stands of ponderosa pine by age class, site quality IV*

| Age of tree (years) | Height growth per inch diameter growth | Height growth per decade | Age of tree (years) | Height growth per inch diameter growth | Height growth per decade | Age of tree (years) | Height growth per inch diameter growth | Height growth per decade |
|---|---|---|---|---|---|---|---|---|
| | *Feet* | *Feet* | | *Feet* | *Feet* | | *Feet* | *Feet* |
| 40 | 5.8 | 9.0 | 140 | 2.1 | 3.7 | 240 | 1.7 | 1.8 |
| 60 | 4.2 | 7.8 | 160 | 2.0 | 3.1 | 260 | 1.6 | 1.6 |
| 80 | 3.3 | 6.8 | 180 | 1.9 | 2.6 | 280 | 1.5 | 1.4 |
| 100 | 2.7 | 5.7 | 200 | 1.8 | 2.3 | 300 | 1.4 | 1.2 |
| 120 | 2.3 | 4.6 | 220 | 1.7 | 2.0 | 320 | 1.3 | 1.1 |

### CHANGE IN FORM AFTER RELEASE

A common conception is that the rapid diameter growth at the base of a tree is not accompanied by similarly rapid diameter growth higher in the tree, and therefore introduces deterioration in form (*29*). This is only half the truth, as has been brought out in a study of the form of ponderosa pine (*24*). In the first place, for a tree of average form, approximately form class [9] 0.70, the diameter growth at half height need be only slightly more than 0.7 of that at breast height for the same form to be maintained. Tree classes having a lower form class were found to grow into this average form after release, and those having higher form class to reduce to it. Several years after cutting, the stands studied were much more homogeneous in form class than at any time previous. Even for a relatively small number of trees chosen at random, the volumes at the time of cut or

[9] The method by which form class is derived is described in the Appendix, p. 52.

at any later time can be estimated from a volume table based upon virgin conditions, providing the distribution of form classes has not been changed materially.

### BARK THICKNESS

A refinement in the technic of computing the growth of individual trees, when diameter at breast height is taken outside the bark, consists in making an allowance for the change in bark thickness. The allowance will increase the apparent growth rates of most stands by about 10 percent. In this study such an allowance was not made, omission to make it being considered a desirable element of conservatism.

Figure 12 shows three plottings of bark thickness, based upon 3,327 trees. One plotting is for the immature trees, classes 1, 2, and

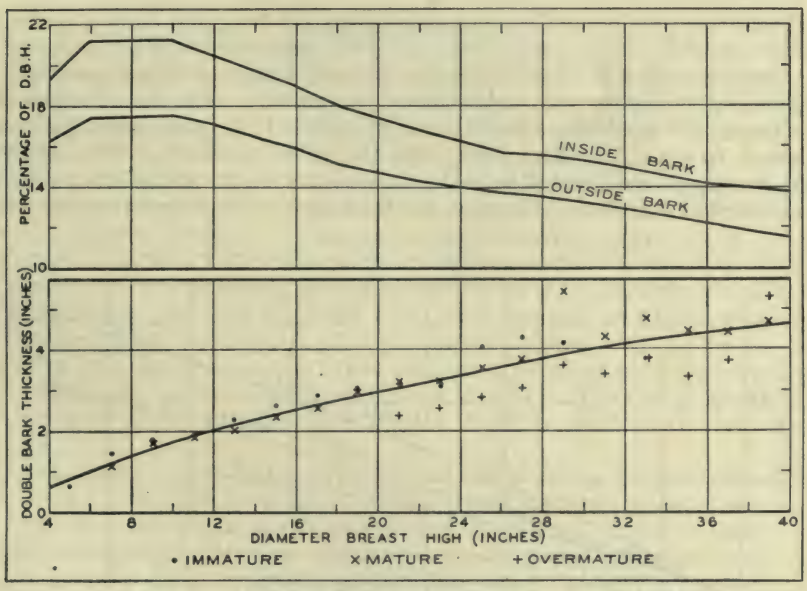



FIGURE 12.—Double bark thickness of ponderosa pine at breast height.

6; the second for the mature trees, classes 3, 4, and 7; and the third for overmature trees, class 5. The first two agree fairly closely and for many purposes can be represented by a single curve, but the bark thickness for class 5 underruns those of the first two classes by one half inch to an inch throughout. Site quality has no effect upon the relative position of the curves.

## THE REPRODUCTION STAND

To be complete, the growth prediction of a selectively cut stand must take the reproduction into account, even though this requires separate treatment. The quantity and distribution of the reproduction largely determine the character of the third and subsequent cuts. In the following sections, some of the essential considerations are taken up.

In ponderosa pine forests, usually a light to dense understory of advance seedlings is present at the time of cutting, and this is aug-

mented slightly by new seedlings following the cutting. Successful natural reproduction is difficult to establish after the cutting is once made. Reproduction existing upon the ground at the time of cutting sometimes is so heavy and develops so well upon release that it assumes the characteristics of an even-aged stand. More or less advance reproduction is found in every well-managed stand. Unfortunately it very often occurs in patches or clumps too dense for proper development. Since natural thinning is a very slow process, in such cases stagnation sets in and a need arises for some form of artificial thinning, either during the logging operations or at any time thereafter. An example of good development of ponderosa pine reproduction is shown in plate 4.

### HEIGHT GROWTH

Ponderosa pine seedlings in uncut stands progress very slowly in height growth (*26*), needing from 20 to 25 years to reach breast height. In cut-over stands the dominant free-growing seedlings grow at a considerably higher rate, as is shown in table 24. On the average site in Oregon the seedlings reach breast height in 12.0 years, taking almost 7 years to grow the first foot. On the plots studied in Washington the seedlings required 7.6 years to reach 1 foot, and 13.5 years to reach breast height. When the 700 seedlings used in these calculations

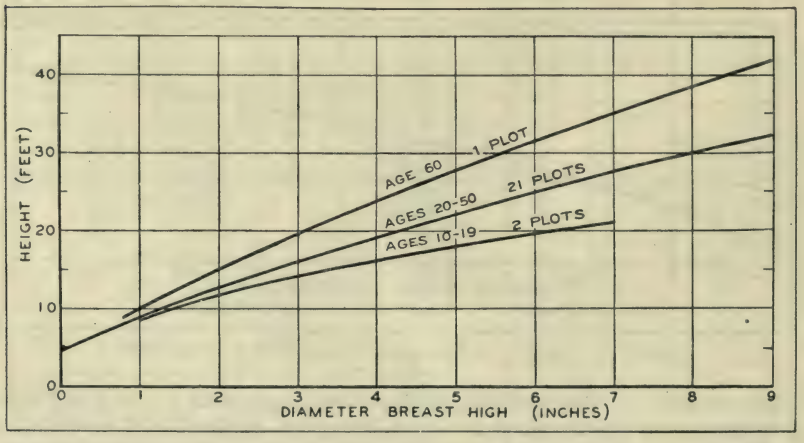



FIGURE 13.—Height-on-diameter relation in reproduction stands in selectively cut ponderosa pine.

were arranged into site-quality classes it was found that the periods required to reach breast height on site qualities IV and V averaged 12.8 years and 14.0 years, respectively.

Figure 13 shows the height curves for average reproduction stands aged 10 to 60 years. For the age classes between 20 and 50 years, height varies only slightly with age, varying to a greater degree with diameter. In true even-aged stands that are not stagnated this condition does not prevail, the height curve on the whole gradually shifting upward. In other words, if the stands for which the data of figure 13 were taken were developing normally the height curves for age classes 20 to 50 years, instead of being nearly coincident, would be spaced at regular intervals; the fact that they almost coincide is evidence of the stands' stagnation.

TABLE 24.—*Growth of dominant ponderosa pine seedlings on site qualities IV and V*

| Site | Years required to grow from ground level to 1 foot | | | Years required to grow from 1 foot to breast height | | | Average number of years required to grow from ground level to breast height |
|---|---|---|---|---|---|---|---|
| | Average | Total range | Standard deviation | Average | Total range | Standard deviation | |
| Oregon: | | | | | | | |
| All sites | 5.2 | 3–16 | 1.9 | 6.8 | 3–18 | 2.6 | 12.0 |
| Washington: | | | | | | | |
| All sites | 5.9 | 3–16 | 2.4 | 7.6 | 2–29 | 3.5 | 13.5 |
| Both States: | | | | | | | |
| Site IV | 5.6 | 3–16 | 2.2 | 7.2 | 2–29 | 3.1 | 12.8 |
| Site V | 6.0 | 3–16 | 2.4 | 8.0 | 2–23 | 3.8 | 14.0 |

### VOLUME GROWTH

The slowness with which the reproduction stand develops is one of the most discouraging phases of the management of selectively cut ponderosa pine forests in the Pacific Northwest. After the first spurt following release, the rate of development of clumps of heavy reproduction lags far behind the rate that is normal for free-growing seedlings and saplings. Examples of reproduction stands that are growing poorly because of stagnation are shown in plate 5. A tally of the reproduction was made on most of the selectively cut plots. On some plots there was no reproduction at all; on a few the reproduction stand covered the entire area. The site quality of the land was determined from the height of the mature timber growing on it, or from the heights of adjacent timber in case the plots were practically clean cut. As previously defined, site quality IV is equivalent to Behre's site index 80 and site quality V is equivalent to his site index 65.

Figure 14, *B* and *C*, shows the volume and average heights of a few fully stocked reproduction stands in selectively cut forests and of several reproduction stands on areas completely cut over. The volumes and heights of the reproduction, shown by the irregular lines and crosses, are compared with the volumes and heights of normally developed even-aged second-growth stands as determined by Behre (*8*).

Both volume and height for average fully stocked stands of reproduction on site quality IV lie far below the normal curves for site quality IV. In fact, they are considerably below those of site quality V. The evidence is striking that the reproduction stands are stagnating and are developing at a rate comparable to the rate that is normal for a site quality 1 to 1½ classes poorer. Overstocking and clumpiness may be the principal causes; the oft-mentioned poor growth conditions of the last decade or two may be also a factor.

Figure 14, *A* is based upon many reproduction tallies, taken in a number of selectively cut stands. It shows how small a volume is being produced, especially in comparison with the full productive capacity of the land as indicated by the normal yield curves in figure 14, *B* and *C*. On the average, the reproduction stand can be counted upon only to produce about 10 percent of the normal yields for site index 80. This situation is deplorable. If stagnation is allowed to persist, it will imperil the cuts at the end of the second and subsequent

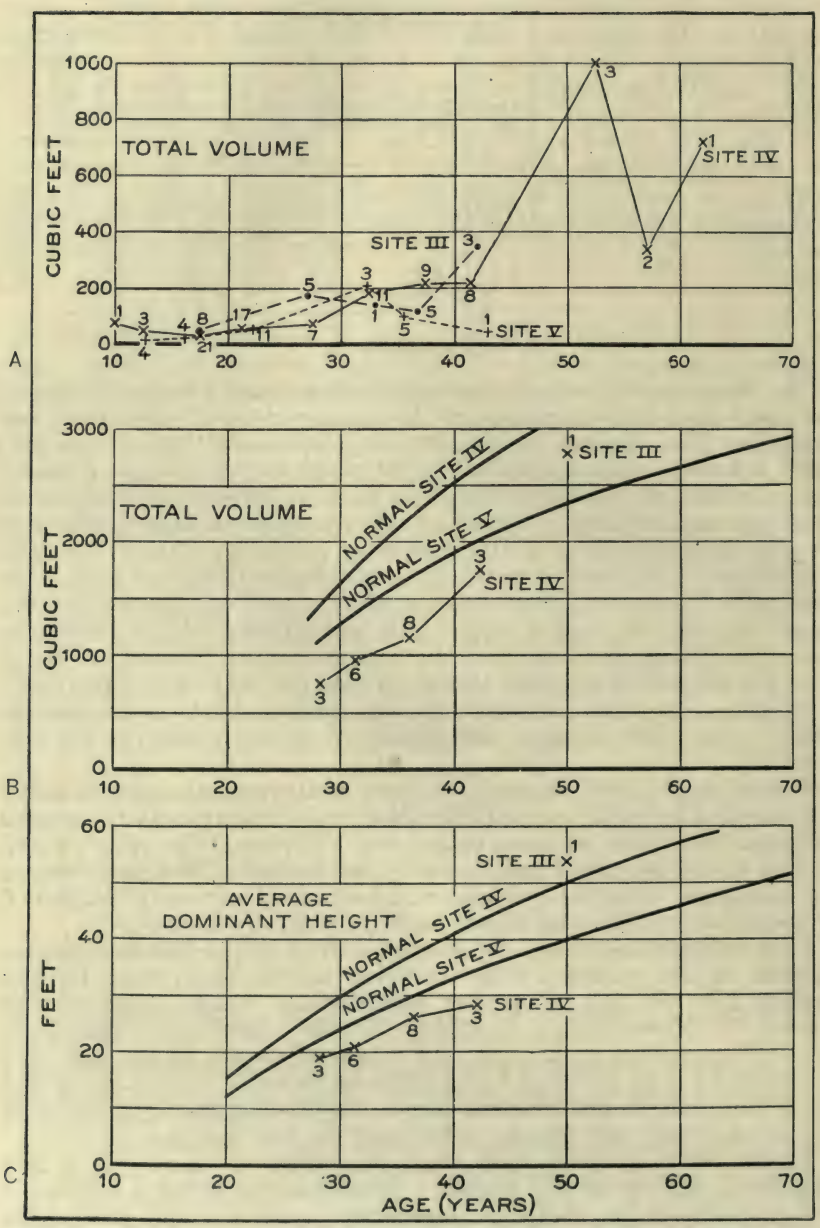



FIGURE 14.—Development of fully stocked and average stands of advance reproduction on selectively cut plots as compared with that of normal even-aged stands that have developed without competition from an overstory: A, average reproduction stand; B and C, fully stocked reproduction stand.

Ponderosa pine stand immediately after a selection cutting, in 1914 (*A*), and 5 years after the cutting, in 1929 (*B*). Much advance reproduction was present in 1914, although it was too small to be discernible in the photograph. In 1929 this reproduction had developed well and was not so dense as to stagnate.

Sapling stands about 30 years old, on land of site quality IV, that are stagnating. Because of overdensity, they are growing only at a rate corresponding to site quality V or poorer. Stand *A*, near Sumpter, Oreg., was left undisturbed after the original heavy selection cutting. Stand *B*, near Cle Elum, Wash., was selectively cut, but was repeatedly recut for fuel wood until the overstory was completely removed.

cutting cycles. Although ponderosa pine reproduction endures stagnation for a long time, it does not do so indefinitely; drought, mistletoe, and insects take their toll, and the remaining saplings are unable to benefit by any liberation that may be given them.

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## APPENDIX

### SUMMARY FORM USED FOR PLOT DATA

The following tabular statement illustrates the final summary form used in this study to give the complete picture of plot development.

PLOT NO. 52.—*Location, Odessa. Nat. For. Crater. Area, 2.0 acres. Yrs. cut, 20*

| | Item | | Stand value | | | | |
|---|---|---|---|---|---|---|---|
| | | | Number trees | Basal area | Cubic feet | Board feet | Average d.b.h. |
| 1 | Original stand per A. | Pine | 42.5 | 101.0 | 4,002 | 24,600 | 20.8 |
| 2 | | Others | 2.5 | 10.6 | 524 | 3,424 | 27.8 |
| 3 | Reserve stand per A. | Pine | 26 | 42.7 | 1,520 | 8,361 | 17.4 |
| 4 | | Others | 0 | | | | |
| 5 | | Percent reserve | 58 | 38 | 34 | 30 | |
| 6 | | Reserve composition by tree class, percent. 1 | 12 | | 6 | 5 | 14.0 |
| 7 | | 2 | 10 | | 2 | | 10.6 |
| 8 | | 3 | 27 | | 42 | 43 | 21.1 |
| 9 | | 4 | 19 | | 14 | 14 | 15.6 |
| 10 | | 5 | 9 | | 31 | 36 | 28.5 |
| 11 | | 6 | 17 | | 2 | | 8.6 |
| 12 | | 7 | 6 | | 3 | 2 | 14.0 |
| 13 | Increment since cutting. | M.A.I. by tree class per A. 1 | | | 2.4 | 12.8 | |
| 14 | | 2 | | | .8 | 6.6 | |
| 15 | | 3 | | | 8.5 | 56.4 | |
| 16 | | 4 | | | 4.0 | 21.8 | |
| 17 | | 5 | | | 3.0 | 20.8 | |
| 18 | | 6 | | | .9 | 3.9 | |
| 19 | | 7 | | | .5 | 1.3 | |
| 20 | | Whole stand per A. | | | 20.1 | 123.6 | |
| 21 | Total loss since cutting per A. | Pine | 2.5 | 3.72 | 124 | 699 | 16.5 |
| 22 | | Others | 1.0 | 3.65 | 166 | 1,060 | 25.8 |
| 23 | Net M.A.I. per A. | Pine | | | 13.9 | 88.6 | |
| 24 | Increment percentages since cutting. | By tree class 1 | | | 2.47 | 3.08 | |
| 25 | | 2 | | | 2.79 | 22.37 | |
| 26 | | 3 | | | 1.33 | 1.58 | |
| 27 | | 4 | | | 1.84 | 1.86 | |
| 28 | | 5 | | | .63 | .68 | |
| 29 | | 6 | | | 3.16 | | |
| 30 | | 7 | | | 1.39 | 1.00 | |
| 31 | | Whole stand | | | 1.32 | 1.48 | |
| 32 | Decadal value per acre. | Decade after cutting 1 | | 47.35 | 1,714 | 9,641 | |
| 33 | | 2 | | 52.36 | 1,922 | 10,833 | |
| 34 | | 3 | | | | | |
| 35 | | 4 | | | | | |
| 36 | | 5 | | | | | |
| 37 | | 6 | | | | | |
| 38 | Value read from growth tables. | Decade after cutting 1 | | 47.1 | 1,680 | 9,280 | |
| 39 | | 1 | | 52.5 | 1,875 | 10,560 | |
| 40 | | 3 | | | | | |
| 41 | | 4 | | | | | |
| 42 | | 5 | | | | | |
| 43 | | 6 | | | | | |
| 44 | Reproduction | Pine | 34 | | | | |
| 45 | | Others by species | 18 | | | | |
| 46 | | Total | 52 | 1.18 | 11.75 | | |

## VOLUME TABLES

Tables 25 to 39 are standard volume tables applicable to ponderosa pine through most of its range except on the very best sites, such as are not found in Oregon and Washington. Tables 27 to 30 give the cubic-foot volume of the entire bole inside bark for mature trees. Tables 31 to 34 and 36 to 39 give board-foot volume to an 8-inch top inside bark for mature trees. Tables 26 and 35 give cubic-foot and board-foot volume for immature trees or bull pine on site quality IV. Table 25 gives cubic-foot volumes applicable to the small sizes in reproduction stands. All the tables are based upon average form, and so will not apply with sufficient accuracy to certain stands that are unbalanced as to form classes. A partial remedy can be found in observing form-class averages. In general, the degree to which the volume of a tree departs from the average

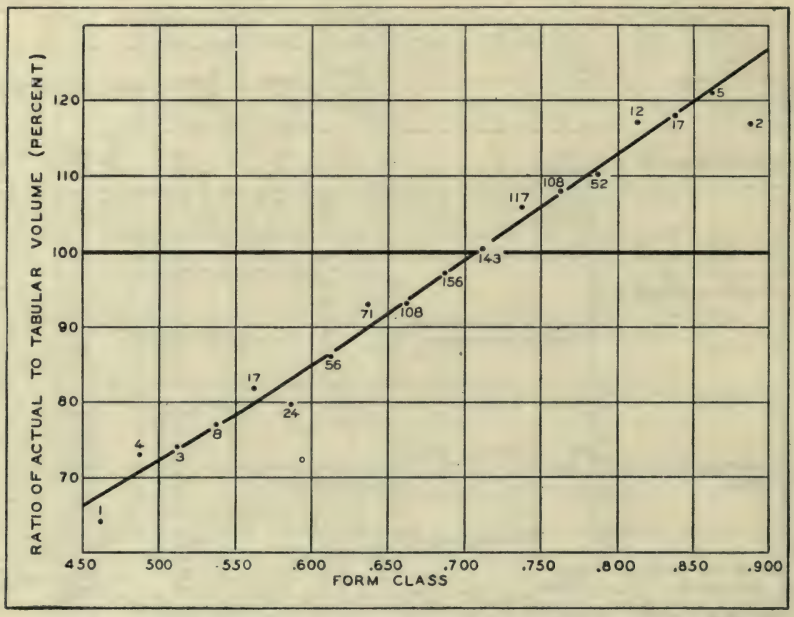


FIGURE 15.—Relation between form class and volume of the average ponderosa pine tree.

depends upon its form class or quotient, a ratio between the diameter inside bark at a point half-way between breast height and the tip and the diameter inside bark at breast height. (For instance, a form class of 0.70 on a tree that has a diameter at breast height inside bark of 15 inches and is 80 feet tall means that the diameter at $\frac{80-4.5}{2}$ feet above breast height or 42.3 feet above the ground is $0.70\times15$ inches, or 10.5 inches.) Figure 15 illustrates the relationship between form class and average volume. Tree class 1 averages about 0.675, classes 2 and 3 about 0.70, and class 4 about 0.725, although in each instance the range on either side of the average may be about 0.15 to 0.20. By determining the average form of 10 to 20 trees selected at random in a stand and using the correction percentage corresponding to it in figure 15, a more accurate estimate can be obtained.

## CUBIC-FOOT VOLUMES

TABLE 25.—*Cubic-foot volume table for small-sized ponderosa pine in reproduction stands*

| Diameter breast high (inches) | Volume (cubic feet) by total height of trees in feet | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 | 35 | 40 |
| 1 | 0.051 | 0.076 | 0.101 | 0.126 | 0.152 | 0.178 | 0.203 |
| 2 | .137 | .206 | .275 | .321 | .412 | .481 | .550 |
| 3 | .252 | .380 | .508 | .635 | .760 | .880 | 1.02 |
| 4 | .40 | .60 | .80 | .99 | 1.20 | 1.39 | 1.59 |
| 5 | .58 | .86 | 1.16 | 1.45 | 1.74 | 2.02 | 2.32 |
| 6 | .82 | 1.22 | 1.63 | 2.04 | 2.45 | 2.85 | 3.26 |
| 7 | 1.08 | 1.62 | 2.17 | 2.70 | 3.25 | 3.77 | 4.32 |
| 8 | 1.38 | 2.00 | 2.75 | 3.45 | 4.15 | 4.85 | 5.55 |
| 9 | 1.73 | 2.58 | 3.45 | 4.35 | 5.20 | 6.05 | 6.90 |
| 10 | 2.10 | 3.15 | 4.20 | 5.25 | 6.30 | 7.35 | 8.40 |

Data collected in reproduction stands in eastern Oregon and eastern Washington. Basis, 84 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by form-factor method, 1930. Aggregate deviation from basic data, −0.11 percent.

TABLE 26.—*Cubic-foot volume table for second-growth ponderosa pine in eastern Oregon and eastern Washington; site quality IV*

| Diameter breast high (inches) | Volume (cubic feet) by total height of tree in feet | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 5 | 1.4 | 2.1 | 2.6 | 3.1 | 3.3 | | | | | | | | |
| 6 | 2.0 | 3.0 | 3.7 | 4.4 | 5.4 | | | | | | | | |
| 7 | 2.7 | 4.0 | 5.0 | 6.0 | 7.2 | | | | | | | | |
| 8 | 3.6 | 5.2 | 6.6 | 7.8 | 9.2 | | | | | | | | |
| 9 | 4.6 | 6.6 | 8.2 | 9.8 | 11.7 | | | | | | | | |
| 10 | 5.8 | 8.1 | 10.0 | 12.0 | 14.0 | | | | | | | | |
| 11 | 7.2 | 9.9 | 12.1 | 14.5 | 16.8 | | | | | | | | |
| 12 | 8.8 | 11.9 | 14.5 | 17.0 | 20.1 | | | | | | | | |
| 13 | 10.1 | 13.9 | 16.6 | 20.1 | 23.8 | 26.9 | 30.0 | | | | | | |
| 14 | 12.0 | 15.9 | 19.5 | 23.7 | 27.2 | 31.0 | 35.8 | | | | | | |
| 15 | 13.9 | 18.2 | 22.8 | 27.0 | 31.9 | 35.5 | 40.0 | 45.0 | 50.5 | | | | |
| 16 | 15.3 | 20.8 | 25.5 | 30.7 | 35.1 | 40.1 | 45.1 | 51.0 | 56.5 | 62.0 | | | |
| 17 | 17.0 | 23.5 | 28.9 | 34.2 | 39.5 | 45.1 | 51 | 57 | 63 | 70 | | | |
| 18 | 19.1 | 25.9 | 31.8 | 37.1 | 44 | 51 | 57 | 63 | 70 | 78 | 86 | | |
| 19 | 22.5 | 29.0 | 35.0 | 41.2 | 48 | 56 | 63 | 70 | 78 | 87 | 96 | | |
| 20 | 24.0 | 32.0 | 39.8 | 46.5 | 53 | 61 | 70 | 78 | 87 | 96 | 106 | 115 | |
| 21 | 26.0 | 35.0 | 43 | 51 | 59 | 67 | 77 | 86 | 95 | 105 | 115 | 125 | 136 |
| 22 | 28.9 | 38.5 | 47 | 56 | 65 | 74 | 84 | 94 | 104 | 114 | 125 | 136 | 149 |
| 23 | 31.2 | 41.5 | 51 | 61 | 71 | 81 | 92 | 103 | 113 | 124 | 138 | 148 | 162 |
| 24 | 33.5 | 45 | 56 | 66 | 77 | 88 | 99 | 111 | 123 | 136 | 150 | 161 | 175 |
| 25 | | 50 | 61 | 72 | 84 | 96 | 107 | 120 | 133 | 147 | 162 | 176 | 189 |
| 26 | | 54 | 66 | 78 | 92 | 104 | 116 | 130 | 145 | 159 | 176 | 189 | 205 |
| 27 | | 58 | 71 | 85 | 100 | 112 | 125 | 140 | 156 | 172 | 188 | 205 | 220 |
| 28 | | 63 | 77 | 92 | 107 | 121 | 135 | 151 | 168 | 185 | 200 | 220 | 240 |
| 29 | | 68 | 84 | 100 | 115 | 130 | 145 | 162 | 181 | 198 | 215 | 235 | 250 |
| 30 | | 73 | 90 | 107 | 124 | 140 | 156 | 174 | 193 | 211 | 230 | 250 | 264 |
| 31 | | 79 | 96 | 115 | 133 | 150 | 167 | 186 | 206 | 225 | 249 | 262 | 280 |
| 32 | | 84 | 103 | 122 | 141 | 160 | 180 | 199 | 218 | 239 | 258 | 276 | 296 |
| 33 | | 90 | 110 | 130 | 150 | 170 | 190 | 210 | 231 | 252 | 272 | 290 | 305 |
| 34 | | 95 | 116 | 137 | 159 | 180 | 200 | 220 | 242 | 265 | 285 | 300 | 315 |
| 35 | | 100 | 121 | 145 | 168 | 190 | 210 | 230 | 252 | 275 | 295 | 310 | 325 |
| 36 | | 105 | 127 | 152 | 177 | 199 | 220 | 240 | 262 | 285 | 305 | 320 | 340 |
| 37 | | 110 | 134 | 159 | 186 | 207 | 230 | 255 | 273 | 295 | 315 | 330 | 350 |
| 38 | | 116 | 141 | 167 | 195 | 215 | 240 | 265 | 285 | 305 | 325 | 345 | 365 |
| 39 | | 123 | 148 | 176 | 205 | 225 | 250 | 275 | 297 | 315 | 340 | 360 | 380 |
| 40 | | 130 | 155 | 185 | 215 | 235 | 260 | 285 | 310 | 330 | 350 | 370 | 390 |

Data collected in eastern Oregon. Basis, 767 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by planimeter method. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, −0.32 percent.

TABLE 27.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 8.6 to 10.0 logs, or medium and good site III, poor site II*

| Diameter breast high (inches) | Volume (cubic feet) by total height of trees in feet | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
| 4 | 0.75 | 1.4 | | | | | | | | | | | | | | | | |
| 5 | 1.3 | 2.15 | | | | | | | | | | | | | | | | |
| 6 | 1.9 | 3.0 | | | | | | | | | | | | | | | | |
| 7 | 2.7 | 4.0 | 4.7 | | | | | | | | | | | | | | | |
| 8 | 3.6 | 5.1 | 6.1 | | | | | | | | | | | | | | | |
| 9 | 4.6 | 6.3 | 7.7 | 9.2 | 10.5 | | | | | | | | | | | | | |
| 10 | 5.6 | 7.7 | 9.5 | 11.2 | 13.0 | | | | | | | | | | | | | |
| 11 | 7.0 | 9.3 | 11.4 | 13.6 | 15.5 | | | | | | | | | | | | | |
| 12 | 8.1 | 10.9 | 13.4 | 15.8 | 18.5 | 21 | 24 | | | | | | | | | | | |
| 13 | 9.6 | 12.6 | 15.3 | 18.5 | 22.0 | 25 | 28 | | | | | | | | | | | |
| 14 | | 14.3 | 18.0 | 22.0 | 25.5 | 29 | 32 | 36 | 40 | | | | | | | | | |
| 15 | | 16.5 | 21 | 25.5 | 29.5 | 34 | 38 | 43 | 48 | | | | | | | | | |
| 16 | | | 24 | 28.5 | 33 | 38 | 44 | 49 | 54 | | | | | | | | | |
| 17 | | | 27 | 32 | 38 | 44 | 50 | 55 | 61 | 66 | 72 | 78 | | | | | | |
| 18 | | | 30 | 36 | 43 | 49 | 56 | 62 | 68 | 75 | 82 | 89 | | | | | | |
| 19 | | | 34 | 41 | 48 | 56 | 63 | 70 | 77 | 84 | 92 | 100 | | | | | | |
| 20 | | | 37 | 45 | 53 | 62 | 69 | 77 | 85 | 93 | 102 | 110 | | | | | | |
| 21 | | | 42 | 50 | 59 | 68 | 76 | 85 | 94 | 103 | 113 | 121 | 128 | 137 | | | | |
| 22 | | | 46 | 55 | 65 | 75 | 84 | 94 | 104 | 113 | 123 | 132 | 140 | 150 | | | | |
| 23 | | | 50 | 60 | 71 | 81 | 92 | 104 | 114 | 123 | 133 | 144 | 153 | 165 | | | | |
| 24 | | | 55 | 66 | 77 | 89 | 101 | 112 | 124 | 134 | 145 | 156 | 167 | 180 | | | | |
| 25 | | | 59 | 72 | 84 | 97 | 109 | 121 | 134 | 144 | 157 | 168 | 181 | 195 | | | | |
| 26 | | | 64 | 78 | 91 | 106 | 118 | 130 | 144 | 156 | 170 | 182 | 195 | 210 | 225 | 240 | | |
| 27 | | | 69 | 84 | 99 | 114 | 126 | 140 | 155 | 168 | 183 | 195 | 210 | 227 | 240 | 255 | | |
| 28 | | | 74 | 91 | 107 | 122 | 136 | 150 | 167 | 181 | 196 | 211 | 228 | 246 | 260 | 275 | | |
| 29 | | | 80 | 98 | 115 | 130 | 147 | 162 | 178 | 195 | 213 | 230 | 248 | 265 | 285 | 300 | | |
| 30 | | | 85 | 105 | 122 | 139 | 157 | 174 | 189 | 207 | 230 | 245 | 265 | 285 | 305 | 320 | | |
| 31 | | | | | 129 | 150 | 167 | 185 | 205 | 224 | 245 | 262 | 285 | 305 | 325 | 340 | 360 | 385 |
| 32 | | | | | 138 | 160 | 178 | 198 | 220 | 241 | 260 | 280 | 305 | 325 | 345 | 365 | 385 | 410 |
| 33 | | | | | 147 | 170 | 189 | 211 | 235 | 255 | 279 | 300 | 325 | 345 | 370 | 390 | 415 | 440 |
| 34 | | | | | 156 | 180 | 200 | 225 | 249 | 270 | 298 | 320 | 340 | 365 | 390 | 415 | 440 | 465 |
| 35 | | | | | 164 | 189 | 210 | 238 | 265 | 285 | 315 | 335 | 360 | 385 | 410 | 440 | 465 | 490 |
| 36 | | | | | 173 | 199 | 223 | 251 | 280 | 302 | 330 | 355 | 380 | 410 | 435 | 465 | 495 | 520 |
| 37 | | | | | 183 | 210 | 236 | 265 | 295 | 320 | 348 | 375 | 400 | 435 | 465 | 490 | 520 | 545 |
| 38 | | | | | 193 | 223 | 250 | 280 | 310 | 338 | 365 | 395 | 425 | 460 | 490 | 520 | 545 | 575 |
| 39 | | | | | 203 | 236 | 265 | 297 | 328 | 355 | 390 | 420 | 450 | 490 | 520 | 545 | 575 | 610 |
| 40 | | | | | 215 | 250 | 282 | 315 | 345 | 380 | 410 | 445 | 480 | 515 | 545 | 575 | 610 | 645 |
| 41 | | | | | | | | | 360 | 397 | 435 | 470 | 500 | 540 | 575 | 610 | 645 | 675 |
| 42 | | | | | | | | | 380 | 420 | 460 | 495 | 525 | 560 | 600 | 640 | 675 | 705 |
| 43 | | | | | | | | | 400 | 440 | 482 | 520 | 555 | 595 | 635 | 675 | 700 | 745 |
| 44 | | | | | | | | | 425 | 465 | 510 | 545 | 583 | 625 | 665 | 705 | 740 | 785 |
| 45 | | | | | | | | | 445 | 490 | 525 | 570 | 610 | 655 | 700 | 740 | 775 | 820 |
| 46 | | | | | | | | | 470 | 510 | 550 | 579 | 640 | 685 | 730 | 770 | 810 | 860 |
| 47 | | | | | | | | | 490 | 530 | 580 | 625 | 670 | 720 | 760 | 810 | 855 | 900 |
| 48 | | | | | | | | | 510 | 550 | 605 | 650 | 700 | 750 | 800 | 850 | 900 | 950 |
| 49 | | | | | | | | | 530 | 575 | 630 | 686 | 725 | 780 | 840 | 895 | 940 | 990 |
| 50 | | | | | | | | | 550 | 600 | 655 | 710 | 752 | 805 | 875 | 925 | 975 | 1,030 |
| 51 | | | | | | | | | 575 | 630 | 685 | 740 | 780 | 850 | 910 | 960 | 1,020 | 1,075 |
| 52 | | | | | | | | | 600 | 660 | 715 | 770 | 820 | 890 | 945 | 1,000 | 1,060 | 1,120 |
| 53 | | | | | | | | | 625 | 680 | 740 | 800 | 860 | 920 | 980 | 1,050 | 1,100 | 1,165 |
| 54 | | | | | | | | | 650 | 710 | 770 | 830 | 900 | 960 | 1,020 | 1,100 | 1,150 | 1,210 |
| 55 | | | | | | | | | 675 | 735 | 800 | 860 | 925 | 995 | 1,070 | 1,140 | 1,200 | 1,260 |
| 56 | | | | | | | | | 700 | 760 | 830 | 900 | 960 | 1,045 | 1,110 | 1,180 | 1,240 | 1,310 |
| 57 | | | | | | | | | 725 | 790 | 860 | 935 | 1,000 | 1,080 | 1,150 | 1,210 | 1,285 | 1,360 |
| 58 | | | | | | | | | 750 | 820 | 900 | 970 | 1,035 | 1,120 | 1,190 | 1,250 | 1,330 | 1,410 |
| 59 | | | | | | | | | 775 | 850 | 930 | 1,010 | 1,070 | 1,160 | 1,230 | 1,300 | 1,380 | 1,460 |
| 60 | | | | | | | | | 805 | 880 | 960 | 1,030 | 1,110 | 1,200 | 1,280 | 1,350 | 1,430 | 1,510 |
| 61 | | | | | | | | | 835 | 910 | 990 | 1,070 | 1,150 | 1,240 | 1,330 | 1,400 | 1,485 | 1,565 |
| 62 | | | | | | | | | 870 | 940 | 1,030 | 1,110 | 1,190 | 1,290 | 1,380 | 1,450 | 1,535 | 1,620 |
| 63 | | | | | | | | | 900 | 970 | 1,070 | 1,150 | 1,240 | 1,340 | 1,430 | 1,500 | 1,590 | 1,670 |
| 64 | | | | | | | | | 930 | 1,000 | 1,110 | 1,200 | 1,280 | 1,390 | 1,480 | 1,550 | 1,645 | 1,720 |
| 65 | | | | | | | | | 960 | 1,040 | 1,150 | 1,250 | 1,320 | 1,440 | 1,530 | 1,600 | 1,700 | 1,780 |

Data collected from Crater, Payette, Lassen, and Plumas National Forests. Basis, 392 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, +0.70 percent.

TABLE 28.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 6.6 to 8.5 logs, or medium and good site IV, poor site III*

| Diameter breast high (inches) | Volume (cubic feet) by total height of trees in feet | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 |
| 4 | 0.3 | 0.7 | 1.3 | 1.8 | 2.3 | 2.6 | | | | | | | | | | |
| 5 | .5 | 1.2 | 2.0 | 2.8 | 3.5 | 4.0 | | | | | | | | | | |
| 6 | .8 | 1.8 | 2.9 | 4.0 | 4.9 | 5.7 | | | | | | | | | | |
| 7 | 1.1 | 2.4 | 3.9 | 5.3 | 6.7 | 7.6 | | | | | | | | | | |
| 8 | 1.5 | 3.2 | 5.1 | 6.9 | 8.6 | 9.8 | | | | | | | | | | |
| 9 | 2.0 | 4.2 | 6.4 | 8.6 | 10.7 | 12.3 | | | | | | | | | | |
| 10 | 2.6 | 5.2 | 8.0 | 10.6 | 13.0 | 15.0 | | | | | | | | | | |
| 11 | | 6.5 | 9.7 | 12.8 | 15.5 | 17.6 | | | | | | | | | | |
| 12 | | 7.8 | 11.5 | 15.2 | 18.0 | 21.0 | 24 | | | | | | | | | |
| 13 | | 9.3 | 13.4 | 17.3 | 21.0 | 24.6 | 28 | | | | | | | | | |
| 14 | | 10.6 | 15.3 | 20 | 24.5 | 28 | 32 | 36 | | | | | | | | |
| 15 | | 12.2 | 17.2 | 23 | 28 | 32 | 37 | 42 | | | | | | | | |
| 16 | | 13.8 | 19.3 | 26 | 31 | 37 | 42 | 48 | 53 | | | | | | | |
| 17 | | 15.3 | 21.8 | 29 | 35 | 41 | 48 | 55 | 60 | | | | | | | |
| 18 | | 16.7 | 24.4 | 32 | 40 | 46 | 54 | 61 | 68 | 74 | 81 | | | | | |
| 19 | | 18.6 | 27 | 36 | 45 | 52 | 61 | 68 | 76 | 83 | 90 | | | | | |
| 20 | | 20.5 | 30 | 40 | 50 | 58 | 67 | 75 | 84 | 93 | 101 | | | | | |
| 21 | | 22.6 | 33 | 45 | 55 | 64 | 74 | 83 | 93 | 103 | 112 | | | | | |
| 22 | | 25 | 36 | 49 | 60 | 70 | 81 | 90 | 102 | 112 | 122 | 132 | 142 | 150 | | |
| 23 | | 27 | 39 | 55 | 66 | 76 | 88 | 100 | 112 | 122 | 133 | 145 | 155 | 165 | | |
| 24 | | | 43 | 59 | 72 | 84 | 97 | 110 | 122 | 134 | 145 | 158 | 170 | 180 | | |
| 25 | | | 47 | 64 | 78 | 92 | 106 | 119 | 132 | 145 | 158 | 172 | 185 | 196 | | |
| 26 | | | 51 | 69 | 85 | 100 | 114 | 129 | 142 | 156 | 172 | 136 | 200 | 211 | | |
| 27 | | | 56 | 75 | 92 | 108 | 123 | 139 | 154 | 170 | 186 | 202 | 215 | 230 | | |
| 28 | | | 61 | 82 | 100 | 117 | 134 | 150 | 167 | 184 | 200 | 217 | 230 | 249 | | |
| 29 | | | 66 | 88 | 108 | 126 | 145 | 162 | 182 | 198 | 215 | 235 | 255 | 270 | | |
| 30 | | | 70 | 95 | 116 | 135 | 155 | 175 | 194 | 212 | 230 | 252 | 272 | 289 | 308 | |
| 31 | | | | 102 | 124 | 144 | 165 | 187 | 207 | 226 | 247 | 272 | 290 | 310 | 330 | |
| 32 | | | | 109 | 132 | 153 | 177 | 200 | 220 | 243 | 266 | 290 | 310 | 332 | 354 | |
| 33 | | | | 116 | 140 | 164 | 188 | 212 | 235 | 260 | 273 | 310 | 332 | 355 | 378 | |
| 34 | | | | 122 | 149 | 174 | 200 | 225 | 250 | 276 | 300 | 330 | 354 | 375 | 400 | |
| 35 | | | | 128 | 158 | 184 | 211 | 237 | 265 | 293 | 320 | 350 | 375 | 400 | 425 | |
| 36 | | | | 135 | 167 | 195 | 222 | 252 | 282 | 310 | 340 | 370 | 396 | 428 | 450 | |
| 37 | | | | | 177 | 206 | 236 | 268 | 298 | 330 | 360 | 390 | 422 | 453 | 475 | |
| 38 | | | | | 188 | 219 | 255 | 285 | 320 | 352 | 384 | 420 | 450 | 480 | 505 | |
| 39 | | | | | 200 | 234 | 270 | 303 | 342 | 375 | 410 | 450 | 478 | 510 | 542 | |
| 40 | | | | | | 249 | 285 | 322 | 362 | 398 | 435 | 474 | 505 | 540 | 570 | 600 |
| 41 | | | | | | 262 | 300 | 343 | 382 | 421 | 460 | 498 | 535 | 570 | 600 | 640 |
| 42 | | | | | | 275 | 320 | 360 | 405 | 443 | 482 | 525 | 560 | 595 | 640 | 680 |
| 43 | | | | | | 290 | 338 | 380 | 428 | 466 | 508 | 550 | 590 | 630 | 665 | 715 |
| 44 | | | | | | 305 | 356 | 400 | 450 | 488 | 536 | 580 | 620 | 660 | 700 | 750 |
| 45 | | | | | | 320 | 372 | 420 | 468 | 510 | 558 | 610 | 650 | 690 | 735 | 785 |
| 46 | | | | | | 337 | 390 | 440 | 488 | 535 | 585 | 640 | 685 | 725 | 775 | 820 |
| 47 | | | | | | 355 | 410 | 460 | 510 | 560 | 615 | 665 | 715 | 760 | 810 | 860 |
| 48 | | | | | | 370 | 430 | 480 | 532 | 585 | 640 | 690 | 750 | 800 | 845 | 900 |
| 49 | | | | | | | 450 | 500 | 555 | 615 | 665 | 720 | 780 | 835 | 880 | 940 |
| 50 | | | | | | | 470 | 520 | 580 | 642 | 695 | 760 | 815 | 865 | 920 | 980 |
| 51 | | | | | | | 490 | 545 | 605 | 670 | 730 | 795 | 850 | 905 | 960 | 1,020 |
| 52 | | | | | | | | 570 | 632 | 695 | 760 | 832 | 885 | 945 | 990 | 1,060 |
| 53 | | | | | | | | 590 | 652 | 725 | 790 | 863 | 920 | 980 | 1,030 | 1,100 |
| 54 | | | | | | | | 610 | 682 | 750 | 825 | 895 | 955 | 1,010 | 1,070 | 1,140 |
| 55 | | | | | | | | 630 | 708 | 785 | 855 | 930 | 990 | 1,045 | 1,110 | 1,180 |
| 56 | | | | | | | | 650 | 735 | 815 | 885 | 960 | 1,020 | 1,085 | 1,150 | 1,220 |
| 57 | | | | | | | | | 770 | 850 | 915 | 990 | 1,050 | 1,125 | 1,190 | 1,260 |
| 58 | | | | | | | | | 805 | 880 | 950 | 1,030 | 1,090 | 1,170 | 1,230 | 1,310 |
| 59 | | | | | | | | | 835 | 920 | 985 | 1,070 | 1,140 | 1,210 | 1,280 | 1,370 |
| 60 | | | | | | | | | 870 | 950 | 1,025 | 1,110 | 1,185 | 1,250 | 1,335 | 1,425 |

Data collected from Crater, Salmon, Lassen, Whitman, Payette, Shasta, Weiser, Boise, Coconino, and Umatilla National Forests. Basis, 4,065 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, −0.0 percent.

TABLE 29.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 4.6 to 6.5 logs, or good site V, poor site IV*

| Diameter breast high (inches) | Volume (cubic feet) by total height of trees in feet | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 5 | 2.0 | 2.4 | 3.0 | 3.7 | | | | | | | | | |
| 6 | 2.8 | 3.5 | 4.3 | 5.3 | | | | | | | | | |
| 7 | 3.7 | 4.8 | 5.8 | 7.2 | | | | | | | | | |
| 8 | 4.7 | 6.2 | 7.6 | 9.2 | | | | | | | | | |
| 9 | 5.9 | 7.8 | 9.6 | 11.5 | | | | | | | | | |
| 10 | 7.2 | 9.5 | 11.8 | 14.0 | | | | | | | | | |
| 11 | 8.7 | 11.3 | 14.0 | 17.0 | | | | | | | | | |
| 12 | 10.0 | 13.3 | 16.8 | 20.0 | 23.0 | 26 | | | | | | | |
| 13 | 11.8 | 15.5 | 19.1 | 23.0 | 26.7 | 30 | 34 | 38 | | | | | |
| 14 | 13.4 | 18.0 | 22.2 | 26.5 | 30.8 | 35 | 40 | 44 | 48 | 53 | 58 | | |
| 15 | 15.5 | 20.5 | 25.5 | 30.5 | 35.2 | 40 | 46 | 51 | 56 | 62 | 67 | | |
| 16 | 17.5 | 23.3 | 28.9 | 34.5 | 40 | 46 | 52 | 58 | 64 | 70 | 75 | 80 | 87 |
| 17 | 19.3 | 26.0 | 32 | 38.5 | 45 | 52 | 59 | 66 | 72 | 78 | 85 | 91 | 98 |
| 18 | 22.0 | 29.0 | 36 | 43 | 51 | 59 | 66 | 74 | 80 | 89 | 96 | 104 | 112 |
| 19 | 24.5 | 32.5 | 40 | 49 | 58 | 67 | 74 | 82 | 90 | 100 | 108 | 117 | 126 |
| 20 | 26.8 | 35.5 | 45 | 54 | 64 | 75 | 82 | 91 | 101 | 111 | 120 | 130 | 139 |
| 21 | 29.5 | 39 | 50 | 60 | 70 | 82 | 90 | 101 | 112 | 123 | 133 | 144 | 154 |
| 22 | 32 | 43 | 55 | 66 | 76 | 89 | 100 | 111 | 124 | 134 | 145 | 157 | 168 |
| 23 | 35 | 47 | 60 | 72 | 83 | 97 | 109 | 122 | 135 | 146 | 159 | 171 | 183 |
| 24 | 38 | 52 | 65 | 78 | 91 | 105 | 119 | 133 | 146 | 158 | 173 | 185 | 200 |
| 25 | 41 | 56 | 70 | 85 | 100 | 115 | 130 | 144 | 158 | 172 | 187 | 202 | 216 |
| 26 | 45 | 61 | 76 | 92 | 108 | 125 | 140 | 156 | 171 | 186 | 203 | 220 | 235 |
| 27 | | | 81 | 100 | 117 | 135 | 150 | 168 | 184 | 201 | 220 | 236 | 253 |
| 28 | | | 88 | 107 | 126 | 145 | 160 | 180 | 198 | 216 | 236 | 253 | 275 |
| 29 | | | 95 | 115 | 136 | 155 | 173 | 195 | 214 | 233 | 255 | 280 | 298 |
| 30 | | | 102 | 124 | 145 | 165 | 186 | 210 | 230 | 250 | 275 | 295 | 318 |
| 31 | | | 110 | 132 | 155 | 177 | 200 | 224 | 245 | 270 | 295 | 315 | 338 |
| 32 | | | 118 | 141 | 165 | 190 | 215 | 238 | 262 | 289 | 314 | 335 | 360 |
| 33 | | | 126 | 150 | 175 | 202 | 230 | 254 | 280 | 306 | 334 | 360 | 385 |
| 34 | | | 133 | 159 | 185 | 214 | 243 | 270 | 298 | 323 | 355 | 380 | 405 |
| 35 | | | 140 | 168 | 195 | 226 | 256 | 286 | 315 | 340 | 375 | 400 | 425 |
| 36 | | | 148 | 177 | 206 | 238 | 270 | 302 | 330 | 360 | 395 | 420 | 450 |
| 37 | | | 155 | 187 | 218 | 250 | 284 | 318 | 350 | 380 | 415 | 440 | 470 |
| 38 | | | 163 | 198 | 232 | 272 | 298 | 337 | 370 | 400 | 438 | 465 | 495 |
| 39 | | | 172 | 209 | 246 | 284 | 313 | 355 | 390 | 420 | 458 | 488 | 520 |
| 40 | | | 182 | 221 | 259 | 296 | 332 | 372 | 410 | 445 | 480 | 515 | 545 |
| 41 | | | 192 | 232 | 273 | 312 | 352 | 390 | 430 | 470 | 505 | 540 | 572 |
| 42 | | | | 243 | 287 | 330 | 370 | 408 | 450 | 490 | 528 | 560 | 600 |
| 43 | | | | 255 | 301 | 347 | 388 | 436 | 470 | 510 | 550 | 585 | 625 |
| 44 | | | | 270 | 315 | 364 | 406 | 454 | 490 | 535 | 575 | 615 | 650 |
| 45 | | | | 287 | 330 | 381 | 425 | 472 | 510 | 555 | 600 | 640 | 680 |
| 46 | | | | 295 | 346 | 398 | 445 | 490 | 530 | 580 | 625 | 670 | 710 |
| 47 | | | | 312 | 363 | 416 | 465 | 510 | 550 | 605 | 650 | 700 | 740 |
| 48 | | | | 330 | 380 | 434 | 485 | 530 | 575 | 630 | 680 | 730 | 770 |
| 49 | | | | | 395 | 452 | 505 | 550 | 600 | 655 | 710 | 760 | 805 |
| 50 | | | | | 410 | 468 | 525 | 570 | 620 | 680 | 740 | 790 | 840 |
| 51 | | | | | 425 | 485 | 545 | 590 | 645 | 705 | 770 | 820 | 870 |
| 52 | | | | | 445 | 505 | 565 | 610 | 665 | 735 | 800 | 850 | 900 |
| 53 | | | | | 460 | 525 | 585 | 635 | 695 | 765 | 825 | 880 | 930 |
| 54 | | | | | 475 | 540 | 600 | 655 | 725 | 795 | 850 | 910 | 960 |
| 55 | | | | | 490 | 560 | 620 | 675 | 755 | 820 | 880 | 940 | 1,000 |
| 56 | | | | | 505 | 580 | 640 | 710 | 785 | 845 | 910 | 970 | 1,035 |
| 57 | | | | | 520 | 600 | 660 | 740 | 810 | 870 | 940 | 1,005 | 1,065 |
| 58 | | | | | 540 | 620 | 680 | 770 | 830 | 895 | 970 | 1,040 | 1,100 |
| 59 | | | | | 555 | 640 | 710 | 800 | 855 | 925 | 1,000 | 1,075 | 1,140 |
| 60 | | | | | 575 | 660 | 740 | 825 | 885 | 960 | 1,040 | 1,110 | 1,180 |

Data collected from Montezuma, Missoula, Carson, San Juan, Coconino, and Bitterroot National Forests. Basis, 6,176 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, +0.5 percent.

TABLE 30.—*Cubic-foot volume table for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain less than 4.5 logs, or site VI, poor and medium site V*

| Diameter breast high (inches) | Volume (cubic feet) by total height of trees in feet | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| 5 | 1.9 | 2.5 | 3.4 | | | | | | | |
| 6 | 2.8 | 3.6 | 4.9 | | | | | | | |
| 7 | 3.9 | 5.0 | 6.6 | | | | | | | |
| 8 | 5.4 | 6.6 | 8.4 | | | | | | | |
| 9 | 6.6 | 8.4 | 10.5 | | | | | | | |
| 10 | 8.4 | 10.2 | 12.8 | 15 | 17 | | | | | |
| 11 | 10.2 | 13.0 | 15.3 | 17 | 20 | | | | | |
| 12 | 13.0 | 15.5 | 17.8 | 20 | 24 | | | | | |
| 13 | 15.0 | 17.5 | 20.5 | 24 | 28 | | | | | |
| 14 | 17.0 | 19.5 | 23 | 28 | 33 | 38 | 43 | | | |
| 15 | 18.9 | 23 | 27 | 31 | 36 | 44 | 50 | | | |
| 16 | 21 | 26 | 30 | 36 | 42 | 50 | 58 | | | |
| 17 | 24 | 29 | 35 | 41 | 48 | 58 | 65 | | | |
| 18 | 27 | 32 | 39 | 46 | 55 | 65 | 73 | 82 | 90 | |
| 19 | 30 | 36 | 43 | 51 | 62 | 73 | 82 | 91 | 101 | |
| 20 | 33 | 40 | 47 | 57 | 69 | 80 | 90 | 102 | 113 | 123 |
| 21 | 37 | 44 | 52 | 64 | 76 | 88 | 100 | 113 | 124 | 134 |
| 22 | 40 | 49 | 58 | 70 | 83 | 96 | 110 | 123 | 135 | 146 |
| 23 | 43 | 54 | 64 | 76 | 90 | 106 | 120 | 133 | 146 | 158 |
| 24 | 47 | 59 | 70 | 83 | 99 | 116 | 129 | 145 | 158 | 173 |
| 25 | | | 76 | 90 | 108 | 124 | 139 | 155 | 171 | 188 |
| 26 | | | 82 | 97 | 116 | 134 | 150 | 167 | 185 | 204 |
| 27 | | | 88 | 105 | 124 | 144 | 160 | 180 | 200 | 220 |
| 28 | | | 95 | 114 | 132 | 154 | 174 | 194 | 214 | 235 |
| 29 | | | 102 | 122 | 141 | 164 | 187 | 210 | 230 | 250 |
| 30 | | | 109 | 130 | 152 | 177 | 200 | 223 | 245 | 268 |
| 31 | | | 117 | 137 | 160 | 189 | 213 | 237 | 260 | 284 |
| 32 | | | 125 | 145 | 170 | 200 | 225 | 252 | 278 | 304 |
| 33 | | | 132 | 154 | 182 | 211 | 235 | 270 | 295 | 325 |
| 34 | | | 138 | 162 | 190 | 223 | 250 | 285 | 311 | 344 |
| 35 | | | 145 | 170 | 200 | 235 | 270 | 300 | 330 | 360 |
| 36 | | | 152 | 180 | 213 | 247 | 285 | 315 | 345 | 380 |
| 37 | | | 159 | 190 | 225 | 265 | 298 | 335 | 365 | 400 |
| 38 | | | 166 | 200 | 235 | 280 | 312 | 350 | 385 | 420 |
| 39 | | | 176 | 212 | 245 | 296 | 335 | 370 | 405 | 440 |
| 40 | | | 187 | 223 | 255 | 310 | 350 | 390 | 428 | 460 |

Data collected from Custer and Black Hills National Forests. Basis, 818 trees. Volume includes peeled stump, stem, and top. Tree volumes computed by Huber's formula from taper curves. Table prepared by alinement-chart method, 1930. Aggregate deviation from basic data, +0.2 percent.

BOARD-FOOT VOLUMES, SCRIBNER RULE

TABLE 31.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 8.6 to 10.0 logs, or medium and good site III, poor site II*

| Diameter breast high (inches) | Volume (board feet) by total height of trees in feet | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 | 200 |
| 10 | 23 | 37 | 54 | | | | | | | | | | | | | |
| 11 | 28 | 45 | 65 | | | | | | | | | | | | | |
| 12 | 34 | 55 | 78 | 103 | | | | | | | | | | | | |
| 13 | 41 | 66 | 91 | 121 | | | | | | | | | | | | |
| 14 | 49 | 78 | 108 | 141 | 173 | | | | | | | | | | | |
| 15 | 57 | 92 | 127 | 163 | 198 | 240 | | | | | | | | | | |
| 16 | 66 | 107 | 146 | 187 | 226 | 270 | 310 | | | | | | | | | |
| 17 | 76 | 123 | 168 | 213 | 257 | 305 | 350 | 390 | 420 | 445 | | | | | | |
| 18 | 87 | 140 | 191 | 240 | 290 | 345 | 395 | 435 | 470 | 500 | | | | | | |
| 19 | 99 | 158 | 214 | 269 | 324 | 385 | 440 | 485 | 525 | 555 | | | | | | |
| 20 | 112 | 178 | 240 | 301 | 360 | 430 | 490 | 540 | 585 | 620 | | | | | | |
| 21 | 125 | 198 | 267 | 335 | 400 | 480 | 540 | 600 | 650 | 690 | 725 | 765 | | | | |
| 22 | 139 | 219 | 295 | 370 | 445 | 530 | 600 | 660 | 720 | 760 | 800 | 845 | | | | |
| 23 | 156 | 242 | 325 | 410 | 485 | 580 | 660 | 725 | 790 | 835 | 880 | 925 | | | | |
| 24 | 173 | 266 | 355 | 450 | 535 | 635 | 725 | 795 | 870 | 915 | 970 | 1,020 | | | | |
| 25 | 191 | 290 | 390 | 490 | 585 | 695 | 790 | 865 | 950 | 1,000 | 1,070 | 1,120 | | | | |
| 26 | 211 | 315 | 430 | 535 | 640 | 755 | 860 | 945 | 1,040 | 1,110 | 1,175 | 1,230 | 1,310 | 1,380 | | |
| 27 | 232 | 345 | 465 | 580 | 700 | 820 | 935 | 1,035 | 1,130 | 1,220 | 1,290 | 1,350 | 1,440 | 1,520 | | |
| 28 | 253 | 370 | 505 | 630 | 760 | 875 | 1,020 | 1,130 | 1,240 | 1,330 | 1,410 | 1,480 | 1,570 | 1,660 | | |
| 29 | 276 | 400 | 550 | 680 | 825 | 955 | 1,115 | 1,230 | 1,350 | 1,450 | 1,540 | 1,625 | 1,710 | 1,810 | | |
| 30 | 300 | 435 | 595 | 740 | 890 | 1,040 | 1,210 | 1,340 | 1,470 | 1,580 | 1,675 | 1,775 | 1,360 | 1,970 | | |
| 31 | | | 640 | 800 | 960 | 1,130 | 1,310 | 1,450 | 1,590 | 1,710 | 1,820 | 1,925 | 2,020 | 2,140 | 2,275 | 2,410 |
| 32 | | | 690 | 860 | 1,040 | 1,220 | 1,415 | 1,570 | 1,720 | 1,850 | 1,970 | 2,075 | 2,190 | 2,320 | 2,465 | 2,600 |
| 33 | | | 740 | 925 | 1,120 | 1,315 | 1,520 | 1,690 | 1,850 | 2,000 | 2,120 | 2,240 | 2,370 | 2,510 | 2,655 | 2,820 |
| 34 | | | 800 | 1,000 | 1,210 | 1,420 | 1,630 | 1,820 | 1,990 | 2,150 | 2,280 | 2,420 | 2,560 | 2,710 | 2,860 | 3,035 |
| 35 | | | 855 | 1,075 | 1,300 | 1,525 | 1,750 | 1,960 | 2,140 | 2,315 | 2,450 | 2,610 | 2,760 | 2,920 | 3,080 | 3,260 |
| 36 | | | 920 | 1,150 | 1,390 | 1,630 | 1,880 | 2,100 | 2,290 | 2,480 | 2,620 | 2,800 | 2,960 | 3,140 | 3,300 | 3,500 |
| 37 | | | 980 | 1,230 | 1,490 | 1,740 | 2,010 | 2,240 | 2,450 | 2,650 | 2,800 | 2,990 | 3,175 | 3,360 | 3,540 | 3,750 |
| 38 | | | 1,055 | 1,320 | 1,590 | 1,860 | 2,140 | 2,380 | 2,620 | 2,825 | 2,990 | 3,180 | 3,390 | 3,590 | 3,790 | 4,000 |
| 39 | | | 1,130 | 1,410 | 1,695 | 1,980 | 2,275 | 2,530 | 2,790 | 3,000 | 3,180 | 3,380 | 3,610 | 3,825 | 4,040 | 4,260 |
| 40 | | | 1,205 | 1,500 | 1,810 | 2,110 | 2,410 | 2,680 | 2,965 | 3,200 | 3,380 | 3,600 | 3,840 | 4,065 | 4,290 | 4,520 |
| 41 | | | | | | | 2,550 | 2,840 | 3,140 | 3,375 | 3,585 | 3,825 | 4,080 | 4,320 | 4,550 | 4,790 |
| 42 | | | | | | | 2,690 | 3,000 | 3,320 | 3,575 | 3,800 | 4,050 | 4,320 | 4,580 | 4,820 | 5,080 |
| 43 | | | | | | | 2,845 | 3,170 | 3,500 | 3,775 | 4,020 | 4,280 | 4,570 | 4,850 | 5,100 | 5,380 |
| 44 | | | | | | | 3,000 | 3,340 | 3,680 | 3,975 | 4,240 | 4,530 | 4,830 | 5,120 | 5,390 | 5,680 |
| 45 | | | | | | | 3,155 | 3,520 | 3,870 | 4,190 | 4,470 | 4,780 | 5,100 | 5,390 | 5,690 | 6,000 |
| 46 | | | | | | | 3,310 | 3,690 | 4,070 | 4,405 | 4,700 | 5,040 | 5,380 | 5,680 | 6,000 | 6,320 |
| 47 | | | | | | | 3,470 | 3,870 | 4,270 | 4,620 | 4,930 | 5,320 | 5,660 | 6,000 | 6,320 | 6,670 |
| 48 | | | | | | | 3,630 | 4,050 | 4,470 | 4,840 | 5,175 | 5,600 | 5,960 | 6,320 | 6,650 | 7,020 |
| 49 | | | | | | | 3,795 | 4,260 | 4,680 | 5,070 | 5,430 | 5,880 | 6,260 | 6,640 | 6,990 | 7,370 |
| 50 | | | | | | | 3,970 | 4,470 | 4,900 | 5,300 | 5,680 | 6,160 | 6,560 | 6,960 | 7,330 | 7,720 |
| 51 | | | | | | | 4,145 | 4,680 | 5,120 | 5,530 | 5,930 | 6,440 | 6,860 | 7,280 | 7,670 | 8,070 |
| 52 | | | | | | | 4,320 | 4,890 | 5,340 | 5,770 | 6,200 | 6,720 | 7,160 | 7,610 | 8,040 | 8,445 |
| 53 | | | | | | | 4,510 | 5,100 | 5,560 | 6,010 | 6,475 | 7,000 | 7,470 | 7,940 | 8,410 | 8,820 |
| 54 | | | | | | | 4,700 | 5,310 | 5,800 | 6,250 | 6,750 | 7,280 | 7,790 | 8,280 | 8,780 | 9,195 |
| 55 | | | | | | | 4,890 | 5,520 | 6,040 | 6,500 | 7,025 | 7,570 | 8,110 | 8,620 | 9,160 | 9,570 |
| 56 | | | | | | | 5,080 | 5,730 | 6,280 | 6,800 | 7,300 | 7,860 | 8,430 | 8,960 | 9,540 | 9,945 |
| 57 | | | | | | | 5,280 | 5,950 | 6,520 | 7,100 | 7,580 | 8,150 | 8,750 | 9,300 | 9,930 | 10,320 |
| 58 | | | | | | | 5,490 | 6,160 | 6,760 | 7,350 | 7,880 | 8,450 | 9,070 | 9,650 | 10,250 | 10,700 |
| 59 | | | | | | | 5,700 | 6,470 | 7,000 | 7,600 | 8,180 | 8,760 | 9,390 | 10,100 | 10,600 | 11,100 |
| 60 | | | | | | | 5,900 | 6,690 | 7,240 | 7,850 | 8,480 | 9,070 | 9,710 | 10,450 | 10,950 | 11,500 |
| 61 | | | | | | | 6,100 | 6,900 | 7,480 | 8,100 | 8,780 | 9,380 | 10,030 | 10,800 | 11,300 | 11,900 |
| 62 | | | | | | | 6,300 | 7,050 | 7,730 | 8,350 | 9,080 | 9,690 | 10,360 | 11,150 | 11,650 | 12,300 |
| 63 | | | | | | | 6,500 | 7,270 | 7,980 | 8,600 | 9,380 | 10,000 | 10,700 | 11,450 | 12,000 | 12,700 |
| 64 | | | | | | | 6,700 | 7,480 | 8,230 | 8,850 | 9,690 | 10,330 | 11,050 | 11,750 | 12,350 | 13,100 |
| 65 | | | | | | | 6,900 | 7,710 | 8,480 | 9,150 | 10,000 | 10,670 | 11,400 | 12,100 | 12,700 | 13,500 |

Data collected from Crater, Payette, Lassen, and Plumas National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 36 for top length, 1930.

TABLE 32.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 6.6 to 8.5 logs, or medium and good site IV, poor site III*

| Diameter breast high (inches) | Volume (board feet) by total height of trees in feet | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 | 160 | 170 |
| 10 | 18 | 32 | 45 | | | | | | | | | | |
| 11 | 26 | 42 | 59 | | | | | | | | | | |
| 12 | 33 | 52 | 75 | 110 | | | | | | | | | |
| 13 | 41 | 65 | 94 | 128 | | | | | | | | | |
| 14 | 50 | 78 | 114 | 150 | 180 | | | | | | | | |
| 15 | 60 | 92 | 133 | 174 | 206 | | | | | | | | |
| 16 | 71 | 108 | 154 | 198 | 235 | 278 | | | | | | | |
| 17 | 84 | 125 | 177 | 225 | 268 | 318 | | | | | | | |
| 18 | 97 | 143 | 200 | 254 | 302 | 360 | 407 | 442 | | | | | |
| 19 | 110 | 162 | 225 | 284 | 338 | 402 | 452 | 498 | | | | | |
| 20 | 124 | 184 | 252 | 315 | 380 | 450 | 505 | 560 | | | | | |
| 21 | 138 | 208 | 280 | 350 | 423 | 500 | 565 | 621 | | | | | |
| 22 | 154 | 233 | 312 | 387 | 466 | 555 | 630 | 690 | 750 | 790 | 840 | | |
| 23 | 171 | 257 | 345 | 427 | 512 | 610 | 692 | 760 | 825 | 872 | 925 | | |
| 24 | 190 | 282 | 380 | 470 | 565 | 675 | 762 | 840 | 910 | 960 | 1, 030 | | |
| 25 | 210 | 310 | 415 | 515 | 622 | 738 | 837 | 925 | 1, 000 | 1, 070 | 1, 140 | | |
| 26 | 232 | 340 | 455 | 562 | 682 | 810 | 910 | 1, 015 | 1, 100 | 1, 180 | 1, 260 | | |
| 27 | 254 | 372 | 496 | 615 | 744 | 880 | 995 | 1, 115 | 1, 210 | 1, 300 | 1, 380 | | |
| 28 | 278 | 406 | 540 | 669 | 808 | 955 | 1, 080 | 1, 220 | 1, 325 | 1, 425 | 1, 510 | | |
| 29 | 304 | 442 | 584 | 726 | 875 | 1, 035 | 1, 180 | 1, 325 | 1, 445 | 1, 550 | 1, 650 | | |
| 30 | 332 | 482 | 632 | 793 | 951 | 1, 130 | 1, 290 | 1, 435 | 1, 575 | 1, 695 | 1, 790 | 1, 880 | |
| 31 | 360 | 524 | 687 | 850 | 1, 025 | 1, 220 | 1, 400 | 1, 560 | 1, 710 | 1, 840 | 1, 945 | 2, 040 | |
| 32 | 390 | 568 | 737 | 918 | 1, 115 | 1, 320 | 1, 515 | 1, 685 | 1, 840 | 1, 980 | 2, 100 | 2, 210 | |
| 33 | 420 | 615 | 795 | 988 | 1, 200 | 1, 425 | 1, 635 | 1, 815 | 1, 975 | 2, 130 | 2, 260 | 2, 380 | |
| 34 | 455 | 664 | 860 | 1, 060 | 1, 300 | 1, 535 | 1, 755 | 1, 960 | 2, 115 | 2, 285 | 2, 430 | 2, 570 | |
| 35 | 495 | 716 | 920 | 1, 140 | 1, 400 | 1, 645 | 1, 890 | 2, 100 | 2, 265 | 2, 455 | 2, 600 | 2, 770 | |
| 36 | 531 | 773 | 988 | 1, 225 | 1, 500 | 1, 755 | 2, 020 | 2, 240 | 2, 425 | 2, 620 | 2, 775 | 2, 970 | |
| 37 | | 832 | 1, 058 | 1, 315 | 1, 600 | 1, 875 | 2, 160 | 2, 380 | 2, 590 | 2, 790 | 2, 965 | 3, 170 | |
| 38 | | 895 | 1, 130 | 1, 410 | 1, 700 | 2, 000 | 2, 300 | 2, 530 | 2, 765 | 2, 970 | 3, 165 | 3, 370 | |
| 39 | | 958 | 1, 205 | 1, 510 | 1, 810 | 2, 120 | 2, 440 | 2, 690 | 2, 945 | 3, 155 | 3, 365 | 3, 590 | |
| 40 | | | 1, 280 | 1, 600 | 1, 925 | 2, 240 | 2, 580 | 2, 850 | 3, 125 | 3, 340 | 3, 570 | 3, 810 | 4, 050 |
| 41 | | | 1, 355 | 1, 700 | 2, 040 | 2, 365 | 2, 715 | 3, 020 | 3, 305 | 3, 530 | 3, 780 | 4, 030 | 4, 300 |
| 42 | | | 1, 435 | 1, 800 | 2, 150 | 2, 490 | 2, 855 | 3, 200 | 3, 485 | 3, 730 | 3, 990 | 4, 260 | 4, 350 |
| 43 | | | 1, 520 | 1, 900 | 2, 260 | 2, 620 | 3, 000 | 3, 370 | 3, 675 | 3, 940 | 4, 200 | 4, 500 | 4, 800 |
| 44 | | | 1, 600 | 2, 000 | 2, 375 | 2, 750 | 3, 150 | 3, 550 | 3, 875 | 4, 150 | 4, 420 | 4, 750 | 5, 050 |
| 45 | | | 1, 685 | 2, 100 | 2, 490 | 2, 880 | 3, 300 | 3, 725 | 4, 080 | 4, 360 | 4, 640 | 5, 000 | 5, 320 |
| 46 | | | 1, 770 | 2, 200 | 2, 600 | 3, 015 | 3, 460 | 3, 900 | 4, 290 | 4, 575 | 4, 880 | 5, 250 | 5, 600 |
| 47 | | | 1, 860 | 2, 300 | 2, 720 | 3, 160 | 3, 625 | 4, 080 | 4, 490 | 4, 800 | 5, 130 | 5, 500 | 5, 900 |
| 48 | | | 1, 950 | 2, 410 | 2, 850 | 3, 310 | 3, 785 | 4, 270 | 4, 700 | 5, 035 | 5, 390 | 5, 775 | 6, 200 |
| 49 | | | | 2, 520 | 2, 980 | 3, 450 | 3, 950 | 4, 470 | 4, 910 | 5, 275 | 5, 650 | 6, 050 | 6, 500 |
| 50 | | | | 2, 630 | 3, 110 | 3, 600 | 4, 120 | 4, 680 | 5, 125 | 5, 500 | 5, 910 | 6, 330 | 6, 800 |
| 51 | | | | 2, 745 | 3, 250 | 3, 760 | 4, 290 | 4, 870 | 5, 340 | 5, 730 | 6, 180 | 6, 610 | 7, 100 |
| 52 | | | | | 3, 400 | 3, 930 | 4, 470 | 5, 070 | 5, 550 | 5, 960 | 6, 450 | 6, 890 | 7, 400 |
| 53 | | | | | 3, 550 | 4, 100 | 4, 660 | 5, 280 | 5, 790 | 6, 210 | 6, 730 | 7, 190 | 7, 700 |
| 54 | | | | | 3, 690 | 4, 270 | 4, 850 | 5, 490 | 6, 030 | 6, 460 | 7, 020 | 7, 500 | 8, 000 |
| 55 | | | | | 3, 840 | 4, 440 | 5, 030 | 5, 695 | 6, 260 | 6, 710 | 7, 310 | 7, 810 | 8, 300 |
| 56 | | | | | 3, 980 | 4, 615 | 5, 210 | 5, 900 | 6, 480 | 6, 970 | 7, 600 | 8, 100 | 8, 600 |
| 57 | | | | | 4, 130 | 4, 795 | 5, 400 | 6, 110 | 6, 700 | 7, 240 | 7, 890 | 8, 400 | 8, 950 |
| 58 | | | | | | 4, 975 | 5, 600 | 6, 330 | 6, 940 | 7, 520 | 8, 170 | 8, 700 | 9, 300 |
| 59 | | | | | | 5, 155 | 5, 800 | 6, 550 | 7, 180 | 7, 800 | 8, 440 | 8, 990 | 9, 650 |
| 60 | | | | | | 5, 330 | 6, 000 | 6, 770 | 7, 430 | 8, 080 | 8, 700 | 9, 250 | 9, 950 |

Data collected from Crater, Salmon, Lassen, Whitman, Payette, Shasta, Weiser, Boise, Coconino, and Umatilla National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 37 for top length, 1930.

TABLE 33.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 4.6 to 6.5 logs, or good site V, poor site IV*

| Diameter breast high (inches) | Volume (board feet) by total height of trees in feet | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 | 130 | 140 | 150 |
| 10 | 18 | 30 | 44 | 63 | | | | | | | | |
| 11 | 23 | 36 | 54 | 76 | 95 | 117 | 140 | 160 | | | | |
| 12 | 28 | 44 | 65 | 91 | 112 | 139 | 166 | 190 | 215 | 236 | | |
| 13 | 34 | 52 | 78 | 107 | 135 | 164 | 194 | 222 | 250 | 274 | | |
| 14 | 40 | 62 | 92 | 125 | 158 | 192 | 226 | 260 | 290 | 317 | | |
| 15 | 47 | 72 | 108 | 147 | 186 | 224 | 260 | 298 | 332 | 366 | | |
| 16 | 54 | 84 | 125 | 170 | 215 | 258 | 300 | 344 | 382 | 420 | 465 | 515 |
| 17 | 63 | 96 | 145 | 195 | 247 | 296 | 340 | 392 | 438 | 480 | 535 | 590 |
| 18 | 72 | 108 | 165 | 220 | 279 | 335 | 385 | 445 | 494 | 545 | 605 | 670 |
| 19 | 82 | 125 | 187 | 250 | 315 | 375 | 439 | 500 | 560 | 615 | 685 | 755 |
| 20 | 92 | 142 | 212 | 282 | 355 | 425 | 494 | 565 | 630 | 692 | 770 | 855 |
| 21 | | 160 | 237 | 314 | 395 | 475 | 552 | 630 | 702 | 772 | 860 | 955 |
| 22 | | 178 | 266 | 352 | 440 | 530 | 615 | 702 | 785 | 860 | 960 | 1,060 |
| 23 | | 200 | 295 | 390 | 486 | 585 | 682 | 780 | 870 | 955 | 1,070 | 1,170 |
| 24 | | 222 | 328 | 430 | 537 | 650 | 756 | 865 | 965 | 1,065 | 1,180 | 1,290 |
| 25 | | 244 | 362 | 470 | 593 | 715 | 832 | 950 | 1,060 | 1,175 | 1,290 | 1,410 |
| 26 | | 267 | 397 | 517 | 650 | 785 | 920 | 1,045 | 1,160 | 1,285 | 1,410 | 1,540 |
| 27 | | 292 | 432 | 566 | 708 | 860 | 1,010 | 1,145 | 1,270 | 1,400 | 1,540 | 1,670 |
| 28 | | 318 | 470 | 618 | 768 | 940 | 1,095 | 1,240 | 1,385 | 1,525 | 1,670 | 1,820 |
| 29 | | 346 | 510 | 670 | 830 | 1,020 | 1,185 | 1,340 | 1,500 | 1,655 | 1,800 | 1,970 |
| 30 | | 376 | 557 | 728 | 895 | 1,100 | 1,280 | 1,450 | 1,640 | 1,790 | 1,950 | 2,120 |
| 31 | | 406 | 602 | 780 | 965 | 1,180 | 1,375 | 1,560 | 1,760 | 1,935 | 2,100 | 2,270 |
| 32 | | 440 | 647 | 840 | 1,035 | 1,265 | 1,470 | 1,680 | 1,885 | 2,075 | 2,250 | 2,430 |
| 33 | | 474 | 695 | 900 | 1,110 | 1,350 | 1,570 | 1,800 | 2,020 | 2,220 | 2,400 | 2,600 |
| 34 | | 510 | 745 | 965 | 1,190 | 1,440 | 1,675 | 1,920 | 2,160 | 2,365 | 2,550 | 2,770 |
| 35 | | | 797 | 1,035 | 1,265 | 1,530 | 1,785 | 2,050 | 2,300 | 2,520 | 2,725 | 2,960 |
| 36 | | | 848 | 1,100 | 1,345 | 1,620 | 1,900 | 2,180 | 2,440 | 2,675 | 2,900 | 3,140 |
| 37 | | | 900 | 1,165 | 1,420 | 1,715 | 2,015 | 2,310 | 2,585 | 2,840 | 3,075 | 3,330 |
| 38 | | | 955 | 1,225 | 1,500 | 1,815 | 2,130 | 2,440 | 2,735 | 3,005 | 3,250 | 3,530 |
| 39 | | | 1,010 | 1,295 | 1,580 | 1,920 | 2,250 | 2,575 | 2,885 | 3,175 | 3,430 | 3,720 |
| 40 | | | 1,065 | 1,365 | 1,670 | 2,025 | 2,370 | 2,710 | 3,040 | 3,345 | 3,615 | 3,920 |
| 41 | | | 1,120 | 1,440 | 1,765 | 2,130 | 2,490 | 2,845 | 3,200 | 3,515 | 3,805 | 4,120 |
| 42 | | | 1,175 | 1,510 | 1,855 | 2,240 | 2,615 | 2,980 | 3,360 | 3,695 | 4,000 | 4,320 |
| 43 | | | 1,235 | 1,580 | 1,950 | 2,350 | 2,745 | 3,125 | 3,520 | 3,875 | 4,200 | 4,540 |
| 44 | | | 1,300 | 1,655 | 2,045 | 2,460 | 2,875 | 3,275 | 3,680 | 4,055 | 4,400 | 4,760 |
| 45 | | | 1,365 | 1,730 | 2,140 | 2,575 | 3,010 | 3,425 | 3,845 | 4,235 | 4,600 | 4,990 |
| 46 | | | 1,430 | 1,810 | 2,235 | 2,690 | 3,145 | 3,575 | 4,015 | 4,420 | 4,810 | 5,230 |
| 47 | | | 1,495 | 1,890 | 2,340 | 2,810 | 3,280 | 3,730 | 4,185 | 4,610 | 5,030 | 5,480 |
| 48 | | | 1,560 | 1,975 | 2,445 | 2,935 | 3,425 | 3,890 | 4,360 | 4,800 | 5,250 | 5,710 |
| 49 | | | 1,630 | 2,060 | 2,550 | 3,065 | 3,575 | 4,050 | 4,540 | 5,000 | 5,480 | 5,960 |
| 50 | | | 1,700 | 2,145 | 2,660 | 3,195 | 3,725 | 4,215 | 4,720 | 5,210 | 5,710 | 6,210 |
| 51 | | | 1,770 | 2,225 | 2,770 | 3,320 | 3,875 | 4,385 | 4,900 | 5,420 | 5,940 | 6,460 |
| 52 | | | | 2,310 | 2,880 | 3,450 | 4,020 | 4,560 | 5,090 | 5,640 | 6,180 | 6,730 |
| 53 | | | | 2,400 | 2,990 | 3,580 | 4,175 | 4,740 | 5,280 | 5,860 | 6,420 | 7,000 |
| 54 | | | | 2,490 | 3,100 | 3,725 | 4,330 | 4,920 | 5,470 | 6,080 | 6,670 | 7,270 |
| 55 | | | | 2,590 | 3,210 | 3,860 | 4,490 | 5,105 | 5,680 | 6,300 | 6,920 | 7,530 |
| 56 | | | | | 3,320 | 4,000 | 4,650 | 5,300 | 5,890 | 6,520 | 7,170 | 7,800 |
| 57 | | | | | 3,435 | 4,140 | 4,810 | 5,495 | 6,100 | 6,750 | 7,425 | 8,070 |
| 58 | | | | | 3,555 | 4,280 | 4,980 | 5,685 | 6,320 | 6,990 | 7,680 | 8,370 |
| 59 | | | | | 3,675 | 4,420 | 5,140 | 5,870 | 6,520 | 7,220 | 7,950 | 8,690 |
| 60 | | | | | 3,795 | 4,560 | 5,300 | 6,050 | 6,740 | 7,450 | 8,220 | 8,960 |

Data collected from Montezuma, Missoula, Carson, San Juan, Coconino, and Bitterroot National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 38 for top length, 1930.

TABLE 34.—*Board-foot volume table (Scribner rule—total height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain less than 4.5 logs, or site VI, poor and medium site V*

| Diameter breast high (inches) | Volume (board feet) by total height of trees in feet | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 40 | 50 | 60 | 70 | 80 | 90 | 100 | 110 | 120 |
| 10 | 16 | 26 | 41 | 58 | | | | | |
| 11 | 21 | 33 | 52 | 74 | | | | | |
| 12 | 26 | 40 | 66 | 91 | | | | | |
| 13 | 31 | 50 | 82 | 110 | | | | | |
| 14 | 38 | 61 | 100 | 130 | 170 | 200 | | | |
| 15 | 46 | 73 | 117 | 154 | 196 | 235 | | | |
| 16 | 55 | 87 | 135 | 175 | 227 | 270 | | | |
| 17 | 66 | 101 | 155 | 207 | 260 | 305 | | | |
| 18 | 78 | 117 | 177 | 236 | 295 | 348 | 410 | 470 | |
| 19 | 91 | 134 | 200 | 268 | 334 | 395 | 465 | 538 | |
| 20 | 104 | 152 | 226 | 304 | 378 | 450 | 520 | 605 | 675 |
| 21 | 116 | 170 | 253 | 340 | 425 | 505 | 595 | 675 | 752 |
| 22 | 130 | 192 | 283 | 380 | 475 | 565 | 660 | 750 | 840 |
| 23 | 144 | 214 | 315 | 420 | 528 | 630 | 730 | 830 | 930 |
| 24 | 158 | 237 | 350 | 465 | 585 | 700 | 815 | 915 | 1,025 |
| 25 | | 262 | 385 | 512 | 645 | 770 | 895 | 1,005 | 1,125 |
| 26 | | 288 | 425 | 562 | 705 | 845 | 980 | 1,100 | 1,225 |
| 27 | | 314 | 465 | 615 | 765 | 920 | 1,070 | 1,190 | 1,325 |
| 28 | | 342 | 505 | 670 | 828 | 1,000 | 1,160 | 1,280 | 1,430 |
| 29 | | 371 | 548 | 727 | 890 | 1,080 | 1,250 | 1,385 | 1,540 |
| 30 | | 400 | 595 | 782 | 956 | 1,160 | 1,345 | 1,485 | 1,655 |
| 31 | | 429 | 640 | 837 | 1,025 | 1,240 | 1,435 | 1,590 | 1,775 |
| 32 | | 458 | 685 | 895 | 1,100 | 1,320 | 1,535 | 1,700 | 1,900 |
| 33 | | 488 | 735 | 955 | 1,170 | 1,400 | 1,640 | 1,815 | 2,025 |
| 34 | | 520 | 790 | 1,015 | 1,240 | 1,490 | 1,745 | 1,935 | 2,150 |
| 35 | | 552 | 840 | 1,080 | 1,315 | 1,585 | 1,850 | 2,060 | 2,275 |
| 36 | | 587 | 895 | 1,145 | 1,390 | 1,680 | 1,950 | 2,180 | 2,400 |
| 37 | | 627 | 950 | 1,210 | 1,470 | 1,775 | 2,070 | 2,300 | 2,530 |
| 38 | | 675 | 1,005 | 1,275 | 1,555 | 1,875 | 2,175 | 2,425 | 2,665 |
| 39 | | 712 | 1,060 | 1,345 | 1,645 | 1,970 | 2,280 | 2,555 | 2,800 |
| 40 | | 755 | 1,125 | 1,420 | 1,730 | 2,070 | 2,390 | 2,680 | 2,935 |

Data collected from Custer and Black Hills National Forests. Stump height 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by adjusting table 39 for top length, 1930.

TABLE 35.—*Board-foot volume tables (Scribner rule—merchantable height) for second-growth ponderosa pine; site IV, eastern Oregon and eastern Washington*

| Diameter breast high (inches) | Volume (board feet) by total number of 16-foot logs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 8 | 20 | 50 | 80 | | | | | | | |
| 9 | 20 | 50 | 85 | | | | | | | |
| 10 | 20 | 55 | 90 | | | | | | | |
| 11 | 25 | 55 | 95 | 135 | | | | | | |
| 12 | 25 | 60 | 105 | 145 | | | | | | |
| 13 | 25 | 65 | 110 | 160 | | | | | | |
| 14 | 25 | 70 | 120 | 180 | 230 | | | | | |
| 15 | 25 | 75 | 135 | 200 | 255 | 325 | | | | |
| 16 | 25 | 85 | 145 | 220 | 285 | 360 | | | | |
| 17 | 25 | 90 | 160 | 240 | 320 | 400 | | | | |
| 18 | 30 | 100 | 175 | 260 | 355 | 445 | 540 | | | |
| 19 | 30 | 110 | 195 | 285 | 390 | 490 | 590 | | | |
| 20 | 30 | 115 | 215 | 315 | 425 | 535 | 645 | | | |
| 21 | 30 | 125 | 235 | 340 | 465 | 585 | 700 | | | |
| 22 | 30 | 135 | 255 | 370 | 510 | 635 | 760 | 920 | | |
| 23 | 30 | 150 | 275 | 405 | 555 | 690 | 830 | 1,000 | | |
| 24 | 35 | 160 | 300 | 440 | 600 | 745 | 900 | 1,075 | | |
| 25 | 35 | 175 | 325 | 480 | 645 | 805 | 970 | 1,160 | | |
| 26 | 35 | 190 | 350 | 520 | 695 | 865 | 1,040 | 1,245 | 1,460 | |
| 27 | 35 | 205 | 375 | 560 | 745 | 930 | 1,120 | 1,335 | 1,560 | |
| 28 | 40 | 220 | 400 | 600 | 800 | 1,000 | 1,205 | 1,430 | 1,660 | |
| 29 | 45 | 235 | 430 | 640 | 860 | 1,070 | 1,295 | 1,530 | 1,760 | |
| 30 | 45 | 255 | 460 | 685 | 920 | 1,140 | 1,385 | 1,635 | 1,870 | 2,140 |
| 31 | | 275 | 490 | 730 | 980 | 1,215 | 1,480 | 1,740 | 1,985 | 2,265 |
| 32 | | 295 | 515 | 775 | 1,040 | 1,290 | 1,575 | 1,845 | 2,100 | 2,395 |
| 33 | | | 545 | 820 | 1,100 | 1,365 | 1,670 | 1,955 | 2,225 | 2,525 |
| 34 | | | 575 | 870 | 1,165 | 1,445 | 1,765 | 2,065 | 2,355 | 2,660 |
| 35 | | | 605 | 920 | 1,230 | 1,525 | 1,860 | 2,175 | 2,485 | 2,795 |

TABLE 35.—*Board-foot volume tables (Scribner rule—merchantable height) for second-growth ponderosa pine; site IV, eastern Oregon and eastern Washington*—Continued

| Diameter breast high (inches) | Volume (board feet) by total number of 16-foot logs | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 36 | | | 630 | 970 | 1,295 | 1,600 | 1,960 | 2,285 | 2,610 | 2,935 |
| 37 | | | 660 | 1,015 | 1,360 | 1,680 | 2,055 | 2,395 | 2,740 | 3,080 |
| 38 | | | 690 | 1,060 | 1,430 | 1,760 | 2,150 | 2,505 | 2,870 | 3,225 |
| 39 | | | 720 | 1,115 | 1,500 | 1,840 | 2,250 | 2,615 | 3,000 | 3,375 |
| 40 | | | 750 | 1,160 | 1,565 | 1,920 | 2,350 | 2,725 | 3,125 | 3,530 |
| 41 | | | 780 | 1,210 | 1,635 | 2,000 | 2,445 | 2,840 | 3,255 | 3,690 |
| 42 | | | 810 | 1,260 | 1,700 | 2,080 | 2,545 | 2,950 | 3,385 | 3,860 |

Data collected from Wallowa and Whitman National Forests. Basis, 186 trees. Stump height, 1.5 feet. Trees scaled in 16-foot lengths with 0.3-foot trimming allowance. Top utilization, 6 to 9 inches inside bark. Table prepared by frustum form factor method, 1925. Aggregate deviation from basic data, −0.69 percent.

TABLE 36.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 8.6 to 10.0 logs, or medium and good site III, poor site II*

| Diameter breast high (inches) | Volume (board feet in tens) by total number of 16-foot logs | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1¼ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Basis (trees) |
| 10 | 3 | 6 | 10 | 14 | 18 | | | | | | | |
| 12 | 4 | 7 | 12 | 17 | 22 | | | | | | | 5 |
| 14 | 5 | 8 | 14 | 21 | 27 | 33 | | | | | | 2 |
| 16 | 6 | 10 | 17 | 25 | 33 | 40 | 47 | 54 | 60 | | | 23 |
| 18 | 7 | 11 | 20 | 30 | 39 | 48 | 56 | 66 | 73 | | | 38 |
| 20 | | 13 | 24 | 36 | 47 | 58 | 69 | 80 | 90 | | | 64 |
| 22 | | 15 | 28 | 42 | 55 | 70 | 82 | 96 | 109 | | | 49 |
| 24 | | 17 | 33 | 49 | 65 | 82 | 98 | 115 | 130 | | | 86 |
| 26 | | 20 | 38 | 58 | 76 | 96 | 116 | 136 | 154 | | | 77 |
| 28 | | 23 | 44 | 67 | 89 | 113 | 136 | 159 | 182 | 205 | | 98 |
| 30 | | | 51 | 77 | 102 | 131 | 158 | 185 | 212 | 240 | | 100 |
| 32 | | | 58 | 88 | 118 | 151 | 182 | 213 | 244 | 275 | 306 | 98 |
| 34 | | | 66 | 100 | 135 | 172 | 208 | 242 | 278 | 313 | 351 | 80 |
| 36 | | | 76 | 113 | 154 | 196 | 236 | 276 | 316 | 358 | 397 | 59 |
| 38 | | | 85 | 127 | 173 | 220 | 265 | 309 | 355 | 402 | 447 | 41 |
| 40 | | | | 142 | 193 | 246 | 295 | 346 | 396 | 448 | 498 | 59 |
| 42 | | | | 158 | 214 | 273 | 328 | 385 | 438 | 498 | 552 | 46 |
| 44 | | | | 175 | 238 | 300 | 363 | 424 | 485 | 552 | 610 | 24 |
| 46 | | | | 192 | 261 | 330 | 398 | 466 | 532 | 605 | 672 | 21 |
| 48 | | | | 210 | 286 | 361 | 436 | 510 | 583 | 664 | 734 | 21 |
| 50 | | | | 229 | 311 | 392 | 473 | 554 | 636 | 722 | 802 | 14 |
| 52 | | | | 247 | 337 | 427 | 515 | 603 | 691 | 783 | 873 | 4 |
| 54 | | | | 266 | 363 | 462 | 555 | 649 | 746 | 845 | 943 | 6 |
| 56 | | | | | | 497 | 599 | 698 | 802 | 907 | 1,010 | 1 |
| 58 | | | | | | 534 | 642 | 747 | 858 | 969 | 1,080 | 1 |
| 60 | | | | | | 572 | 687 | 803 | 916 | 1,030 | 1,160 | 2 |
| 62 | | | | | | 610 | 731 | 857 | 977 | 1,100 | 1,240 | |
| 64 | | | | | | 648 | 775 | 914 | 1,040 | 1,180 | 1,320 | |
| 66 | | | | | | 687 | 820 | 969 | 1,100 | 1,250 | 1,400 | 1 |
| 68 | | | | | | 727 | 869 | 1,020 | 1,170 | 1,320 | 1,470 | |
| 70 | | | | | | 766 | 921 | 1,080 | 1,230 | 1,390 | 1,550 | |
| 72 | | | | | | 805 | 975 | 1,130 | 1,300 | 1,460 | 1,630 | |
| Basis (trees) | | 12 | 18 | 95 | 170 | 250 | 192 | 192 | 73 | 15 | 3 | 1,020 |

Block indicates extent of basic data. Data collected from Crater, Payette, Lassen, and Plumas National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot logs with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by frustum form factor method, 1928. Aggregate deviation from basic data, −0.4 percent. Average deviation, 13.0 percent.

TABLE 37.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 6.6 to 8.5 logs, or medium and good site IV, poor site III*

| Diameter breast high (inches) | Volume (board feet in tens) by total number of 16-foot logs | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1¼ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Basis (trees) |
| 10 | 3 | 6 | 10 | 14 | | | | | | | 3 |
| 12 | 4 | 7 | 12 | 17 | 22 | | | | | | 56 |
| 14 | 5 | 8 | 15 | 21 | 27 | 34 | | | | | 123 |
| 16 | 6 | 10 | 18 | 26 | 34 | 41 | 49 | | | | 201 |
| 18 | 7 | 12 | 21 | 31 | 40 | 49 | 59 | | | | 332 |
| 20 | 8 | 13 | 25 | 37 | 48 | 60 | 72 | | | | 421 |
| 22 | 9 | 16 | 30 | 44 | 58 | 73 | 86 | 100 | | | 565 |
| 24 | 10 | 18 | 35 | 52 | 70 | 87 | 104 | 121 | | | 605 |
| 26 | | 21 | 41 | 61 | 81 | 102 | 123 | 145 | 165 | | 548 |
| 28 | | 24 | 47 | 71 | 95 | 120 | 145 | 170 | 195 | | 560 |
| 30 | | 28 | 55 | 82 | 110 | 140 | 169 | 199 | 227 | | 370 |
| 32 | | 32 | 63 | 94 | 126 | 162 | 195 | 229 | 261 | | 371 |
| 34 | | 36 | 71 | 107 | 145 | 184 | 222 | 260 | 298 | 335 | 273 |
| 36 | | 40 | 80 | 122 | 164 | 209 | 251 | 295 | 336 | 381 | 207 |
| 38 | | 45 | 90 | 136 | 184 | 234 | 282 | 328 | 375 | 425 | 123 |
| 40 | | | 100 | 151 | 204 | 260 | 313 | 365 | 417 | 471 | 97 |
| 42 | | | 110 | 167 | 226 | 286 | 345 | 402 | 460 | 523 | 42 |
| 44 | | | | 184 | 250 | 315 | 380 | 443 | 509 | 576 | 32 |
| 46 | | | | 201 | 272 | 345 | 415 | 485 | 556 | 633 | 16 |
| 48 | | | | 219 | 297 | 375 | 453 | 530 | 608 | 692 | 7 |
| 50 | | | | 237 | 322 | 408 | 490 | 575 | 659 | 748 | 4 |
| 52 | | | | 256 | 349 | 441 | 531 | 624 | 714 | 818 | 3 |
| 54 | | | | 275 | 375 | 475 | 573 | 671 | 770 | 870 | |
| 56 | | | | | 402 | 510 | 616 | 723 | 827 | 934 | |
| 58 | | | | | 431 | 546 | 660 | 771 | 882 | 995 | 1 |
| 60 | | | | | 460 | 584 | 704 | 823 | 937 | 1,060 | |
| 62 | | | | | 489 | 622 | 749 | 875 | 997 | 1,130 | |
| 64 | | | | | 519 | 661 | 794 | 932 | 1,060 | 1,200 | |
| 66 | | | | | 550 | 701 | 840 | 992 | 1,120 | 1,280 | |
| Basis (trees) | 12 | 102 | 338 | 663 | 1,257 | 1,449 | 891 | 219 | 27 | 2 | 4,960 |

Block indicates extent of basic data. Data collected from Crater, Salmon, Lassen, Whitman, Payette, Shasta, Weiser, Boise, Coconino, and Umatilla National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by frustum form factor method, 1928. Aggregate deviation, +0.4 percent. Average deviation, 14.8 percent.

TABLE 38.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain 4.6 to 6.5 logs, or good site V, poor site IV*

| Diameter breast high (inches) | Volume (board feet in tens) by total number of 16-foot logs | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1¼ | 2 | 3 | 4 | 5 | 6 | 7 | 8 | Basis (trees) |
| 10 | 3 | 6 | 10 | | | | | | 36 |
| 12 | 4 | 7 | 12 | 18 | | | | | 398 |
| 14 | 5 | 9 | 15 | 22 | 28 | | | | 603 |
| 16 | 6 | 10 | 18 | 27 | 34 | 42 | | | 770 |
| 18 | 7 | 12 | 22 | 32 | 42 | 52 | | | 855 |
| 20 | 8 | 14 | 26 | 39 | 51 | 64 | 75 | | 835 |
| 22 | 10 | 17 | 31 | 46 | 62 | 78 | 91 | | 808 |
| 24 | 11 | 20 | 37 | 56 | 74 | 94 | 112 | | 773 |
| 26 | | 23 | 44 | 66 | 89 | 112 | 134 | | 651 |
| 28 | | 27 | 52 | 78 | 105 | 132 | 160 | 186 | 508 |
| 30 | | 31 | 60 | 90 | 121 | 154 | 187 | 218 | 379 |
| 32 | | 35 | 68 | 103 | 139 | 177 | 214 | 250 | 278 |
| 34 | | 39 | 77 | 116 | 157 | 200 | 242 | 282 | 157 |
| 36 | | 43 | 87 | 129 | 176 | 224 | 270 | 315 | 97 |
| 38 | | 48 | 95 | 144 | 195 | 248 | 297 | 348 | 54 |
| 40 | | | 104 | 158 | 215 | 272 | 326 | 382 | 29 |
| 42 | | | 114 | 173 | 235 | 298 | 357 | 417 | 23 |
| 44 | | | 124 | 189 | 257 | 325 | 391 | 455 | 12 |
| 46 | | | 135 | 205 | 279 | 353 | 425 | 495 | 9 |
| 48 | | | | 223 | 303 | 384 | 462 | 538 | 8 |
| 50 | | | | 240 | 328 | 415 | 500 | 583 | 5 |
| 52 | | | | 259 | 354 | 449 | 540 | 632 | 1 |
| 54 | | | | 278 | 380 | 483 | 580 | 678 | |
| 56 | | | | 298 | 408 | 518 | 622 | 727 | |
| 58 | | | | 319 | 435 | 554 | 665 | 777 | 2 |
| 60 | | | | 340 | 462 | 590 | 710 | 830 | |
| 62 | | | | 361 | 491 | 627 | 755 | 884 | |
| 64 | | | | 382 | 520 | 666 | 800 | 939 | |
| Basis (trees) | 143 | 593 | 2,066 | 2,545 | 1,542 | 348 | 50 | 4 | 7,291 |

Block indicates extent of basic data. Data collected from Montezuma, Missoula, Carson, San Juan, Coconino, and Bitterroot National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches inside bark. Table prepared by frustum form factor method, 1928. Aggregate deviation from basic data, −0.6 percent. Average deviation, 14.8 percent.

TABLE 39.—*Board-foot volume table (Scribner rule—merchantable height) for mature ponderosa pine; sites on which the tallest 10 percent of the trees contain less than 4.5 logs, or site VI, poor and medium site V*

| Diameter breast high (inches) | Volume (board feet in tens) by total number of 16-foot logs | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1¼ | 2 | 3 | 4 | 5 | 6 | Basis (trees) |
| 10 | 4 | 6 | | | | | 8 |
| 12 | 4 | 8 | 13 | | | | 134 |
| 14 | 5 | 9 | 16 | 24 | | | 151 |
| 16 | 6 | 11 | 19 | 28 | 37 | | 178 |
| 18 | 8 | 13 | 23 | 34 | 45 | 56 | 126 |
| 20 | 9 | 15 | 28 | 42 | 55 | 68 | 108 |
| 22 | 10 | 18 | 34 | 51 | 67 | 84 | 57 |
| 24 | 12 | 21 | 41 | 61 | 81 | 102 | 30 |
| 26 | | 25 | 48 | 72 | 96 | 121 | 4 |
| 28 | | 29 | 56 | 84 | 112 | 142 | 2 |
| 30 | | 33 | 64 | 96 | 128 | 164 | |
| 32 | | 37 | 72 | 108 | 146 | 186 | |
| 34 | | 41 | 81 | 121 | 165 | 209 | |
| 36 | | 45 | 89 | 134 | 183 | 233 | |
| 38 | | 49 | 98 | 148 | 202 | 257 | |
| 40 | | 54 | 107 | 163 | 221 | 282 | |
| Basis (trees) | 19 | 165 | 325 | 247 | 41 | 1 | 798 |

Block indicates extent of basic data. Data collected from Custer and Black Hills National Forests. Stump height, 1.5 feet. Trees scaled in 16-foot log lengths with 0.3-foot trimming allowance. Top utilization, 8 inches. Table prepared by frustum form factor method, 1928. Aggregate deviation from basic data, +0.6 percent. Average deviation, 15 percent.

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# A STUDY OF THE RAW COTTON AND THE YARN AND SHEETING MANUFACTURED FROM THREE GRADES OF AMERICAN UPLAND COTTON

BY

The Bureau of Agricultural Economics and
The Bureau of Home Economics
In Cooperation with Clemson
Agricultural College

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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By the *Bureau of Agricultural Economics* and the *Bureau of Home Economics in cooperation with Clemson Agricultural College*

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## SETTING OF THE PROBLEM

By ROBERT W. WEBB

The principles underlying the program of standardization of cotton quality of the Department of Agriculture are predicated upon the relationships which undoubtedly exist between the properties of cotton fibers and their spinning behavior or efficiency, on the one hand, and between the properties of cotton fibers and the quality of the yarns and fabrics manufactured from them, on the other. Presumably, many different fiber properties are concerned in quality. Practical standards have been promulgated, however, only for length of staple, for grade, and for preparation of long-staple cotton (*45*,[1] *51*, *52*).[2] That the staple and grade standards, so far as they go, have proved themselves to be of much service is evidenced by the fact that they are now

[1] Italic numbers in parentheses refer to Literature Cited, p. 66.

[2] UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF AGRICULTURAL ECONOMICS. HANDBOOK FOR LICENSED CLASSIFIERS (United States Cotton Standards Act). 30 pp. Washington, D.C. [Mimeographed.]

in common use not only throughout this country but in every other country of the world where American cotton is used in large quantities.

Because of the lack of scientific data upon which to base an accurate system of cotton classification and of the probable time it would require to obtain them, the original basis of the standards and of their graduations necessarily was sought in the experience of the trade, and in the capacities of practical cotton judges to recognize quality variations. Although relations of staple length of raw cotton to the strength and fineness of yarns are generally recognized, they are neither thoroughly understood nor mathematically evaluated.[3] Studies have been made by Willis on the relation of the grade of cotton to its spinning behavior, visible waste, yarn properties, and fabric quality (*55*), but only fragmentary information of an experimental nature is available on the relation of quality of the raw cotton, as indicated by classification, to wearing quality and serviceability of the resulting fabrics.

It was this need of such technical data that prompted, in 1928, the beginning of a cooperative effort between the Bureau of Agricultural Economics and the Bureau of Home Economics to make a more complete study of white cottons selected to represent a relatively wide range of grades. It seemed desirable to know not only the properties of the raw cottons, their behaviors during subjection to the manufacturing processes, and the quality of their yarns and fabrics but also the reactions of the finished products when subjected to service, laundering, and ironing. Sheeting was chosen because of the relative simplicity of its construction and the possibilities of giving it uniform and controlled service.

The initial study reported in this bulletin has embraced American upland White cotton from the Texas area, crop of 1928–29, representing, according to the Universal Standards, a bale of each of the grades of Good Middling, Middling, and Strict Good Ordinary, and, according to the official staple types, approximately 1 inch in staple length. The procedure employed in the manufacture of the sheeting and the observations pertaining to the behavior of the cottons during manufacture and to some properties of the raw cottons and of their intermediate products, yarns, and fabrics are presented in the second part of the bulletin. The studies that deal with the serviceability and the resistance of the fabrics to ironing conditions are reported in the third and fourth parts, respectively.

## THE MANUFACTURING PROCEDURE AND SOME PROPERTIES OF THE RAW COTTON, INTERMEDIATE PRODUCTS, YARNS, AND FABRICS[4]

By HORACE H. WILLIS and ROBERT W. WEBB[5]

In the Universal Standards for grades of cotton, three elements of quality, namely, color, leaf and other foreign matter, and prepara-

[3] WEBB, R. W. COTTON QUALITY: WHAT DO WE KNOW ABOUT IT? U.S.Dept.Agr., illus. 1933. [In preparation for a multigraphed publication.]

[4] This study is a part of the program of work of the Division's Cotton Utility and Standards Research Section now under the leadership of R. W. Webb. The yarns and sheetings were manufactured at the Textile School, Clemson Agricultural College, S.C., with textile facilities made available to the Department of Agriculture by the college through cooperative arrangement and under the supervision of H. H. Willis while in charge of the section's spinning activities.

[5] Appreciation is expressed to M. E. Campbell, P. G. Gillespie, W. H. Gray, J. J. Brown, and F. R. Logan, of the spinning laboratory, for assistance rendered and to members in

tion are considered (*45*, *51*, *52* [6]). The possible instability of color, the graduations of the three factor ranges, and the pitch of the different scales give rise to a number of fundamental and practical problems. Some matters of major interest, for example, are the importance of color; the degree to which differences of color in raw cottons reflect themselves through manufactured products in the gray, bleached, and variously dyed states; and the nature and extent to which the grade standards furnish a precise index of the manufacturing utility of a cotton, other things being equal, with respect to staple length and character insofar as the present concepts of these quality factors are concerned. It is recognized, however, that, in addition to the quality of the raw cotton employed, the organization, conditions, and procedure of manufacture, the construction of the manufactured product, and its intended purpose constitute other technical factors which, in various ways and degrees, may influence the quality of resulting cotton goods, the cost of their manufacture, and the evaluation of the quality of the raw cotton.

In an effort to furnish comparable material and data as a background for assistance in determining the importance of those quality elements embraced in or associated with the grade standards, three bales of cotton selected to represent a relatively wide range of grades for so-called "White American upland cotton" have been manufactured under the best controlled and comparable conditions available and have been studied with respect to certain fiber, yarn, and fabric properties. A description of the materials, conditions, and procedure employed in the experimental manufacture of the sheetings and the information obtained from those studies are presented here.

## MATERIALS AND METHODS

### SELECTION AND EXAMINATION OF THE COTTONS

Since portions of each of the three bales finally selected were to be manufactured into a sheeting, it was desirable to select cottons of such character and staple as to conform as closely as possible to those used in greatest quantity for sheeting. Investigation showed that at the time of this experiment, as a rule, a "hard" cotton about 1 inch in staple length was used. Three bales of approximately the same staple and character but representing three different grades were purchased from a local market at Houston, Tex. Care was exercised that each bale within itself be as nearly uniform as possible in character, leaf, foreign matter, preparation, color, staple length, and regularity of fiber length, as discussed by Palmer (*45*). To this end, each bale was "fanned" at the head (by removing the tie near the top end) and the lint was examined every 3 inches for uniformity of grade, staple, and character.

At the spinning laboratory when the bagging and ties were removed from each cotton a large sample was taken from near the top, middle, and bottom of each of the three bales in an effort to obtain

other laboratories of the section, specifically to Dorothy Nickerson for brilliance determinations, spectrophotometric measurements, and assistance in revising the manuscript; to A. C. Jones for length measurements; to Etta Zeh and H. B. Richardson for yarn, fabric, and moisture tests; and to Carl M. Conrad for suggestions and assistance in revising the manuscript.

[6] UNITED STATES DEPARTMENT OF AGRICULTURE, BUREAU OF AGRICULTURAL ECONOMICS. See footnote 2.

three samples that would furnish a true and comparable basis for study of the different cottons. These samples were submitted to the Appeal Board of Review Examiners of the United States Department of Agriculture, Washington, D.C., for classification. The Board found the samples to be of Good Middling, Middling, and Strict Good Ordinary grades, respectively, the Middling sample, however, having a slightly rougher preparation than the other two. They called the staple length of the Good Middling and Strict Good Ordinary samples 1 inch, but two times out of three they called the Middling sample 1 1/32 inches, the other time 1 inch. The board found the samples to be regular with respect to staple, medium with respect to body, and normal with respect to strength. These designations represent average characteristics. So far as the board is able to determine, the samples from the three grades did not differ from each other with respect to any of these character elements. The cottons will be identified in subsequent tables not only by their respective grade designations but also numerically by the positions of each in the scale of the nine grades for White cotton beginning with the highest grade.

It is evident from the above descriptions that cottons representing a considerable range in grade were obtained. The finding of the Board that the Middling sample was slightly longer was confirmed by fiber length arrays. As shown subsequently, however, this difference in length, because of its small magnitude, could not have accounted for much of the relatively higher strength of the products from this bale; nevertheless, these slight differences well might be kept in mind when considering the results from the Middling bale.

Color measurements showed that, in comparison with a set of averages of measurements for the nine White grades of the official standards of the United States, the Good Middling bale was bright but not creamy; in fact, its color was close to that of a bright Strict Middling. The Middling bale was creamier than the average and near the upper range of this grade. The color of the Strict Good Ordinary bale was close to the average for this grade.

### MANUFACTURING CONDITIONS AND PARTICULARS

In general, the organization and machine speeds and settings were the same for the three cottons and conform to those customarily used by commercial plants for the manufacture of sheetings.

When the ties and bagging had been removed from the bales a quantity of cotton from each was weighed and passed through an opener. These quantities were then placed in separate bins and allowed to condition for at least 24 hours, after which they were reweighed and passed through the following machines:

| | |
|---|---|
| Picker room | Breaker picker.<br>Finisher picker. |
| Card room | Card.<br>Drawing frames (two processes).<br>Roving frames (three processes). |
| Spinning room | Ring spinning frame. |

For the manufacture of the sheeting, two counts were spun: 21s with a twist multiplier of 4.50 for the warp yarns and 26s with a

twist multiplier of 3.75 for the filling yarns. For comparative purposes, 21s warp yarns also were spun with twist multipliers of 4.25 and 4.75. In addition, 28s warp yarns were spun with the same 3 twist multipliers to provide further information, since cottons of this staple length are usually considered suitable for counts in this range. The organization, speeds, and settings employed for the manufacture of each of the three selected cottons into yarn are shown in tables 1 and 2.

TABLE 1.—*Organization and speeds of machines used in the manufacture of yarns from the 3 selected cottons*

| Machine | Organization | | | Speeds | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weight per yard or size | Doubling | Draft | Feed roll | Beater | Fan | Blows per inch | | | | |
| Pickers: | *Ounces* | *Number* | *Number* | *R.p.m.* | *R.p.m.* | *R.p.m.* | *Number* | | | | |
| Breaker | 13.75 | | | 14.0 | [1] 977 | 1,327 | 7.4 | | | | |
| Finisher | 11.00 | 4 | 5.00 | 6.5 | [2] 1,377 | 1,408 | 45.0 | | | | |
| | | | | Lickerin | Cylinder | Doffer | | | | | |
| Cards | *Grains* 46.0 | 1 | 104.62 | *R.p.m.* 464 | *R.p.m.* 168 | *R.p.m.* 10 | | | | | |
| | | | | Front roll | Calendar roll | | | | | | |
| Drawing frames: | | | | *R.p.m.* | *R.p.m.* | | | | | | |
| First | 47.5 | 6 | 5.81 | 365 | 279 | | | | | | |
| Second | 49.0 | 6 | 5.82 | 366 | 285 | | | | | | |
| | | | | Front roll | Spindle | Twist setting | | | | | |
| | | | | | | Turns per inch | Multiplier | | | | |
| Roving frames: | *Hanks* | | | *R.p.m.* | *R.p.m.* | *Number* | *Number* | | | | |
| Slubber | 0.736 | 1 | 4.33 | 181 | 620 | 0.92 | 1.07 | | | | |
| Intermediate | 1.95 | 2 | 5.30 | 170 | 963 | 1.60 | 1.15 | | | | |
| Fine | 5.50 | 2 | 5.64 | 132 | 1,360 | 3.09 | 1.32 | | | | |
| | | | | Spindle | | | | Front roll | | | |
| | | | | 3.75 T.m.[4] | 4.25 T.m. | 4.50 T.m. | 4.75 T.m. | 3.75 T.m. | 4.25 T.m. | 4.50 T.m. | 4.75 T.m. |
| Ring spinning frames: | | | | | | | | | | | |
| Warp yarns: | *Counts* | | | *R.p.m.* | *R.p.m.* | *R.p.m.* | *R.p.m.* | *R.p.m.* | *R.p.m.* | *R.p.m.* | *R.p.m.* |
| Frame A [3] | 21 | 2 | 7.64 | ------- | 9,500 | 9,500 | 9,500 | ------- | 156 | 145 | 138 |
| Frame B [3] | 21 | 2 | 7.64 | ------- | ------- | 8,500 | ------- | ------- | ------- | 128 | ------- |
| Filling yarns | 26 | 2 | 9.45 | 6,200 | ------- | ------- | ------- | 103 | ------- | ------- | ------- |
| Do | 28 | 2 | 10.18 | ------- | 9,250 | 9,250 | 9,250 | ------- | 133 | 122 | 118 |

[1] Porcupine beater.
[2] 2-blade beater.
[3] Frame A was used for the spinning test yarns and approximately half the warp yarns. Frame B was used for the remainder of the warp yarns.
[4] T.m.=twist multiplier.

TABLE 2.—*Settings of the machines used in the manufacture of yarns from the 3 selected cottons*

| Machine | Settings | | |
|---|---|---|---|
| | Feed roll to beater | Grids from beater (top) | Grids from beater (bottom) |
| | *Inches* | *Inches* | *Inches* |
| Breaker picker | 3/16 | 1/2 | 1/2 |
| Finisher picker | 3/16 | 5/16 | 1 1/16 |

| Cards | *Gage* [1] |
|---|---|
| Feed plate to lickerin | 10 |
| Mote knives (top) | 15 |
| Mote knives (bottom) | 12 |
| Lickerin to cylinder | 7 |
| Back plate to cylinder (top) | 29 |
| Back plate to cylinder (bottom) | 34 |
| Flats to cylinder (back) | 9 |
| Flats to cylinder (center) | 9 |
| Flats to cylinder (front) | 9 |
| Front plate to cylinder (top) | 29 |
| Front plate to cylinder (bottom) | 34 |
| Doffer to cylinder | 7 |
| Doffer comb to doffer | 22 |
| Lickerin screen (front) | 29 |
| Lickerin screen (back) | 17 |
| Cylinder screen (back) | 29 |
| Cylinder screen (center) | 34 |
| | *Inch* |
| Cylinder screen (front) | 3/16 |

| Machine | Drawing rolls [2] | | |
|---|---|---|---|
| | First to second roll | Second to third roll | Third to fourth roll |
| | *Inches* | *Inches* | *Inches* |
| First and second drawing frames | 1 1/4 | 1 7/16 | 1 5/8 |
| Roving frames: | | | |
| Slubber | 1 7/32 | 1 3/8 | |
| Intermediate | 1 3/16 | 1 3/8 | |
| Fine | 1 5/32 | 1 5/16 | |
| Spinning frames: | | | |
| For Middling cotton: | | | |
| Top rolls | 1 1/8 | 1 1/4 | |
| Bottom rolls | 1 1/16 | 1 1/4 | |
| For Good Middling and Strict Good Ordinary cotton: | | | |
| Top rolls | 1 1/16 | 1 1/4 | |
| Bottom rolls | 1 | 1 1/4 | |

[1] Thousandths of an inch.
[2] Measured from center to center of rolls.

The following machines were used to prepare the warp yarns for weaving: Winder, warper, and slasher.

Inasmuch as the available laboratory equipment was not of a size to permit the warping and slashing of the yarns, these processes were carried out by a commercial plant.[7]

The sheetings were woven on an 82-inch plain loom, making 108 picks per minute. The following specifications were followed as closely as possible in making the gray sheetings:

Yarns—21s warp and 26s filling (single yarns).
Construction—64 warp and 64 filling threads per inch.
Width—72 inches.
Weight—1.94 linear yards per pound.

[7] Acknowledgment is made to J. R. Clark, superintendent of Kenneth Cotton Mills, Walhalla, S.C., for services rendered in preparing the warps.

The treatment given the fabrics at the finishing plant[8] was as follows: Kier boiling with 3 percent caustic soda solution at 30 pounds steam pressure; souring with three fourths to 1 percent sulphuric acid solution, chemicking with one fourth of 1 percent available chlorine solution, thorough washing preparatory to finishing, water mangling, starch mangling, drying, dampening, calendering, and manufacturing into sheets.

The ingredients used in the starching operation consisted of a combination of cornstarch and a saponified tallow softening material.

During the manufacture of the three cottons at the spinning and weaving laboratories, the relative humidity was held as nearly constant as possible by means of an automatically controlled humidifying system in each room. The appropriate humidifying heads were turned on 1 or more hours before beginning the daily operation of each machine and they were allowed to operate, as governed by the controls, until the end of the working day or the time when the machines were stopped. The controls were adjusted to maintain 50 percent relative humidity in the picker room, 60 percent in the card room, 70 percent in the spinning room, and 67 percent in the weave room. Although the relative humidity employed in the weave room was slightly lower than that usually adopted by commercial plants, the records show that the number of stoppages for broken warp ends was for the most part very low. In this case, therefore, it was not necessary to maintain a higher relative humidity. During the manufacture of the yarns, hourly readings were made of wet- and dry-bulb temperatures as recorded by psychrometers, located in each room. Similar observations were made in the weave room by means of a sling psychrometer. The averages of the dry-bulb temperatures so obtained, the percentages of relative humidity calculated from the temperature readings, and the time required for processing are shown in table 3. The regain determined for samples of stock taken at the various manufacturing processes is shown in table 4.

TABLE 3.—*Averages of hourly readings of room temperature and of percentage of relative humidity during processing, and number of hours required for each type of machine used in the manufacture of sheeting from the 3 selected cottons*

| Machine | Good Middling (No. 3) | | Middling (No. 5) | | Strict Good Ordinary (No. 8) | | Time required for processing |
|---|---|---|---|---|---|---|---|
| | Temperature | Relative humidity | Temperature | Relative humidity | Temperature | Relative humidity | |
| | ° F. | *Percent* | ° F. | *Percent* | ° F. | *Percent* | *Hours* |
| Opener | 74 | 51 | 81 | 51 | 73 | 50 | 2 |
| Pickers | 76 | 51 | 77 | 51 | 72 | 50 | 6 |
| Card | 73 | 60 | 74 | 60 | 72 | 60 | 19 |
| Drawing frame [1] | 71 | 60 | 73 | 60 | 72 | 60 | 19 |
| Roving frame [2] | 73 | 60 | 73 | 60 | 74 | 60 | 61 |
| Spinning frame [3] | 72 | 70 | 71 | 70 | 72 | 70 | 13 |
| Loom | 73 | 66 | 80 | 68 | 80 | 67 | 100 |

[1] Average for 2 processes.
[2] Average for all hanks.
[3] Average for both counts of yarn.

[8] Appreciation is expressed to S. M. Fessenden, general manager, and W. F. Odom, general superintendent, of the Sayles Biltmore Bleacheries, Biltmore, N.C., for cooperation extended in finishing the fabrics and making the sheets in September 1929.

TABLE 4.—*Percentage of moisture regain in samples taken at different processes in the manufacture of sheeting from the 3 selected cottons*

| Kind of sample | Moisture regain | | |
|---|---|---|---|
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| | *Percent* | *Percent* | *Percent* |
| Raw stock (bale) | 6.38 | 8.46 | 7.64 |
| Raw stock (bin) | 6.67 | 7.82 | 4.87 |
| Breaker picker lap | 6.44 | 7.35 | 6.50 |
| Finisher picker lap | 6.89 | 6.78 | 6.55 |
| Card lap [1] | 6.50 | 6.30 | 5.63 |
| Card sliver [1] | 6.61 | 6.55 | 5.35 |
| Drawing sliver [1] | 5.88 | 6.84 | 5.97 |
| Fine frame roving | 6.78 | 5.99 | 6.16 |
| Roving in spinning creel [2] | 7.56 | 7.73 | 7.04 |
| Yarn [2] | 7.88 | 7.99 | 7.44 |

[1] Average of 2 samples.
[2] Average of 2 samples reeled and weighed immediately.

## METHODS

(1) Moisture regain: Samples weighing 20 grams each were taken at the beginning and at successive stages throughout the manufacture of the yarns. These samples were dried to a constant weight in an oven at 221° to 230° F. according to the methods recommended by the American Society for Testing Materials (*3*). The regain is obtained by expressing the loss in weight as a percentage of the dry weight of the sample.

(2) Fiber length: Samples from the raw material and from the products of successive stages of manufacture were sorted according to length on the Suter-Webb sorter, as described by Webb (*54*), and the length at the 25-percent point in the cumulative weight-length array, reading from the longest fibers, was used as a basis for comparison. The results obtained by two or more sortings were averaged.

(3) Percentage of waste: At each manufacturing process in which the removal of waste is of primary importance, weighings were made of stock fed, stock delivered, and each type of waste removed. From these data the percentages of waste for each of the three lots of cotton were calculated. The small discrepancy usually noted between the weight of stock fed and the sum of the weights of stock delivered and waste recovered is accounted for by invisible loss or gain. Such losses or gains usually contribute so small a percentage of the waste content of cottons that they may be regarded as relatively insignificant.

(4) Strength of yarns (skein): 25 sample bobbins of each twist and number of warp yarn spun were used for strength and size tests.[9] Skeins of 120 yards each were reeled from the bobbins and allowed to condition for at least 3 hours in an atmosphere of 65 percent relative humidity at 70° F. Each skein was then broken on a standard type, motor-driven yarn tester and sized on a

[9] The tests were made in the laboratories of the Division of Cotton Marketing at Washington, D.C.

direct yarn-numbering quadrant.[10] Since it generally is impossible, for a number of reasons, to spin a specified size of yarn, the breaking strengths were adjusted to the specified size according to the usual custom by assuming that, within small limits, they are inversely proportional to the size.

(5) Strength of yarns (single strand): Five bobbins each of 21s and 28s warp yarn spun with a 4.50 twist multiplier from each of the three lots were conditioned for about 4 hours in an atmosphere of 65 percent relative humidity at a temperature of 70° to 73° F. Approximately one hundred and fifty 12-inch lengths of yarn from each bobbin were broken successively on a Moscrop automatic single-strand yarn tester.

On this machine a 12-inch strand of yarn is grasped at one end by a movable jaw, the other end being attached to a calibrated spiral spring. Tension is applied to the yarn and to the spiral spring

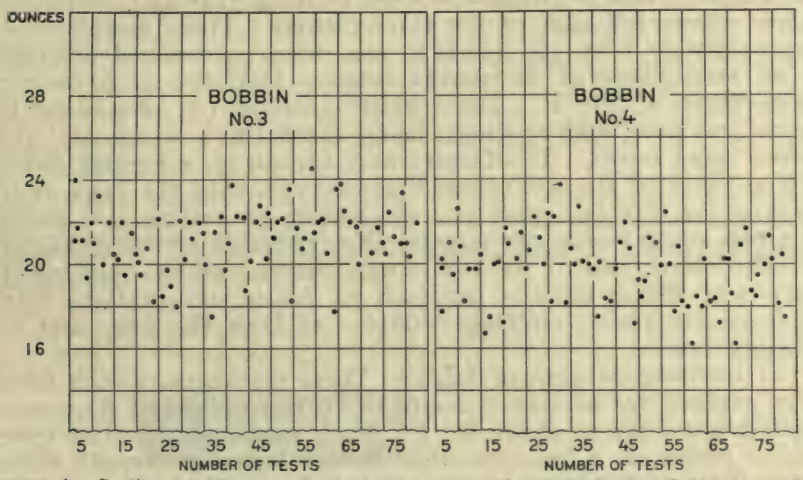


FIGURE 1.—Section of Moscrop chart showing strength of single-strand 21s yarn, 4.75 twist multiplier, spun from the selected cotton of Middling (No. 5) grade.

until the yarn breaks. When this occurs, the maximum elongation of the spring is recorded on a chart by means of a needle point which pierces the chart, the results being read directly in ounces. Figure 1 shows a section of the type of chart used in connection with this machine.

In this test the data recorded on the perforated chart were later assembled in tabular form, and the average strength of yarn of each lot was calculated. The averages thus calculated were corrected for the exact yarn number (21s or 28s) by assuming that, within their ranges, the strength of the yarn is inversely proportional to the count. In making the corrections the average sizes of the 25 skeins of 21s and 28s yarn, respectively, spun with a 4.50 twist multiplier, were used.

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[10] When the balance does not indicate the size directly, the yarn size or number may be calculated from the formula:

$$\text{Yarn size or number} = \frac{\text{Length in yards of single yarn}}{\text{Weight in grains}} \times \frac{7{,}000 \text{ (grains in 1 pound)}}{840 \text{ (yards per hank of cotton yarn)}}$$

(6) Brilliance: Measurements of brilliance were made on the raw material and on products of successive stages of manufacture by means of a Keuffel & Esser disk colorimeter. The instrument and the method have been described by Nickerson, (*41*, *42*, *43*). Briefly, it consists in so adjusting the area of a set of four color disks that the light coming from them is equal in hue, brilliance, and chroma to that coming from the sample. The colors from the disks are mixed by a rotating prism, and adjustment is facilitated by comparing the light from the two sources on adjacent half-circular fields. The expression of brilliance is made in equidistant units from black to white, as illustrated in the Munsell Book of Color (*38*).

(7) Spectrophotometric measurement: Spectrophotometric measurements were made on a Keuffel & Esser color analyzer, the reflections at different wave lengths being expressed as a fraction of those from a magnesium carbonate block, as described by Keuffel (*31*).

(8) Tensile strength of fabrics: Fifteen samples of fabric were cut warpwise and 15 fillingswise from both the gray and the finished fabric woven for each of the three cottons. Three samples, each approximately 7 by 1¼ inches in size, were conditioned overnight in an atmosphere of 65 percent relative humidity at a constant temperature of 70° F. The "strip" method (*3*) of testing the fabric was used, each specimen being raveled to a width of 1 inch before being tested. The fabrics were broken on a regular power-driven tester of the inclination balance type, with the jaws of the machine set 3 inches apart and the bottom or pulling jaw moving at a rate of 12 inches per minute. For purposes of correction, the actual constructions of the cloths were determined by counting the warp and filling threads per inch of fabric, observations being made in six places on large samples of both the gray and the bleached fabrics.

(9) Bursting strength of fabrics: Three specimens of each fabric were exposed for at least 3 hours in an atmosphere of 65 percent relative humidity at about 73° F. Each specimen was then tested in five places on a hand-operated Mullen bursting-strength tester. From the data for bursting strength per square inch thus obtained an average was calculated.

## RESULTS OF TESTS

### PERCENTAGE OF WASTE REMOVED AT CERTAIN PROCESSES

The percentages of each type of waste removed from each of the cottons by the pickers and card, based on net weight of cotton fed to these particular machines, are listed in table 5. Figure 2 shows graphically the percentages of the fractionated and total wastes based on the weight of cotton fed to the opener breaker.

Examining the results for total visible waste for the three 1-inch cottons, it is observed that a waste of 6.40 percent was obtained for the Good Middling grade; 6.06 percent for the Middling; and 12.99 percent for the Strict Good Ordinary. The percentages for Good Middling and Strict Good Ordinary are well within the range of those usually obtained for such grades under similar picking and carding conditions. That for the Middling cotton, however, may be considered somewhat low for this grade. These comparisons are

made on a basis of a large amount of data compiled at the spinning laboratory and of observations elsewhere.

TABLE 5.—*Percentages of the different types of waste removed by the pickers and the card in the manufacture of the 3 selected cottons*

| Kind of waste | Waste percentage [1] | | |
|---|---|---|---|
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| Picker waste: | | | |
| Breaker: | *Percent* | *Percent* | *Percent* |
| Visible | 0.57 | 0.43 | 1.94 |
| Invisible | [2] .09 | .33 | .53 |
| Finisher: | | | |
| Visible | .85 | .68 | 2.54 |
| Invisible | .13 | .06 | .24 |
| Card waste: | | | |
| Flat strips | 2.36 | 2.67 | 3.20 |
| Cylinder and doffer strips | .49 | .61 | .76 |
| Motes and fly | 2.07 | 1.73 | 5.03 |
| Sweepings | .13 | .03 | .05 |
| Total visible | 5.05 | 5.04 | 9.04 |
| Total invisible | .31 | .42 | .51 |
| Picker and card waste: | | | |
| Total visible | 6.40 | 6.06 | 12.99 |
| Total invisible | .35 | .80 | 1.24 |

[1] The waste percentage for each cleaning machine is based on the net weight of cotton fed to that particular cleaning machine. The percentage of total visible waste removed by the pickers and card equals 100 times the sum of the pounds of waste removed by the pickers and card divided by the net weight fed to the opener picker. Invisible waste is figured similarly.
[2] Invisible gain.

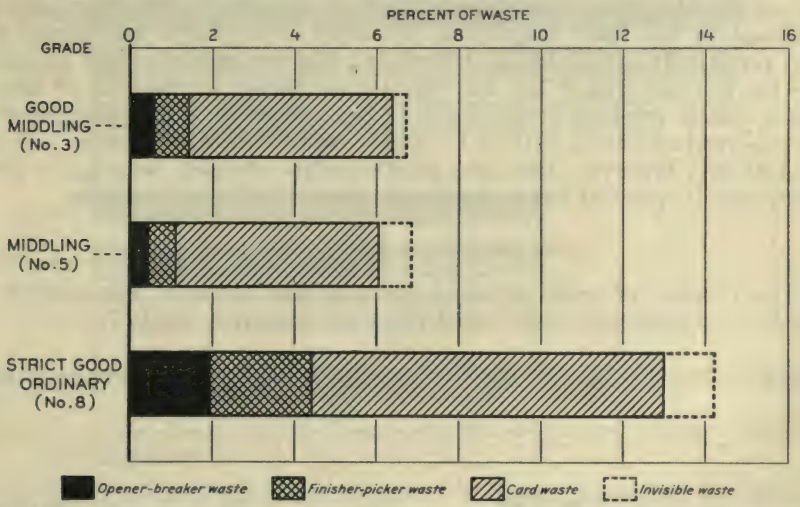


FIGURE 2.—Percentages of picker and card waste from the three selected cottons. (Based on net weight fed to opener.)

## CHANGES IN FIBER LENGTH DURING MANUFACTURE INTO YARN

The lengths of fiber at the 25 percent point in the cumulative weight-length arrays for samples of the raw cotton and for those

taken at certain stages of processing from each of the three cottons tested are shown in table 6.

TABLE 6.—*Length of fiber in the raw stock and products from certain successive stages in the manufacture of 21s warp yarn from the 3 selected cottons*

| Kind of sample | Length of fiber [1] | | |
|---|---|---|---|
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| | *Inches* | *Inches* | *Inches* |
| Raw stock | 1.001 | 1.022 | 0.986 |
| Breaker picker lap | 1.003 | 1.025 | .991 |
| Finisher picker lap | .998 | 1.077 | 1.007 |
| Fine frame roving | 1.015 | 1.069 | 1.017 |
| Yarn | .593 | 1.010 | .964 |

[1] Length calculated at the 25 percent point in the cumulative weight array, reading from the longest fibers.

The standard error of the difference between any two reported lengths is about plus or minus 0.018 inch. With this figure in mind, it is seen that the fiber length of the different products from the Good Middling cotton did not change significantly during the course of manufacture, nor did the Strict Good Ordinary cotton change significantly prior to the spinning process. The Middling cotton fiber length appears to have increased at the finisher picker lap and to have decreased again during the spinning process. But the small quantity of waste removed is not sufficient to explain this apparent increase in length at the finisher picker. Besides, no corresponding increase in the fiber lengths of the other two grades was noted at this point. It is concluded, therefore, that the greater fiber lengths for the finisher picker lap and fine frame roving in the case of Middling cotton resulted from slight errors, either in the measurements on the products or in failure to obtain representative samples. It is of interest, however, that the relationships of fiber lengths in the yarns are in general agreement with those in the raw cottons.

### END BREAKAGE DURING SPINNING

The number of ends breaking per hundred spindles per hour for the 21s yarns of 4.50 twist multiplier are shown in table 7.

TABLE 7.—*End breakage per hundred spindles per hour during spinning of the 3 selected cottons*

| Count of yarn | End breakage [1] | | |
|---|---|---|---|
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| | *Ends* | *Ends* | *Ends* |
| 21s | 0.65 | 0.84 | 1.41 |

[1] Approximately 2,100 to 2,400 spindle hours involved in each case.

The results for the three selected cottons are seen to increase directly as the grade becomes lower.

### STRENGTH AND IRREGULARITY OF WARP YARNS (SKEIN)

The breaking strengths of skeins prepared from 21s and 28s warp yarns for each twist multiplier for each of the 3 grades are shown in table 8. The skein strengths are plotted in figure 3.

TABLE 8.—*Average strength of yarn per skein for the 3 selected cottons*

| Count of yarn | Twist multiplier | Strength of yarns | | |
|---|---|---|---|---|
| | | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| | | *Pounds* | *Pounds* | *Pounds* |
| 21s | 4.25 | 115.0 | 115.7 | 97.0 |
| | 4.50 | 114.5 | 114.4 | 98.2 |
| | 4.75 | 113.8 | 112.2 | 96.7 |
| Average | | 114.4 | 114.1 | 97.3 |
| 28s | 4.25 | 78.0 | 79.2 | 64.7 |
| | 4.50 | 79.5 | 78.3 | 65.9 |
| | 4.75 | 78.6 | 79.0 | 64.5 |
| Average | | 78.7 | 78.8 | 65.0 |

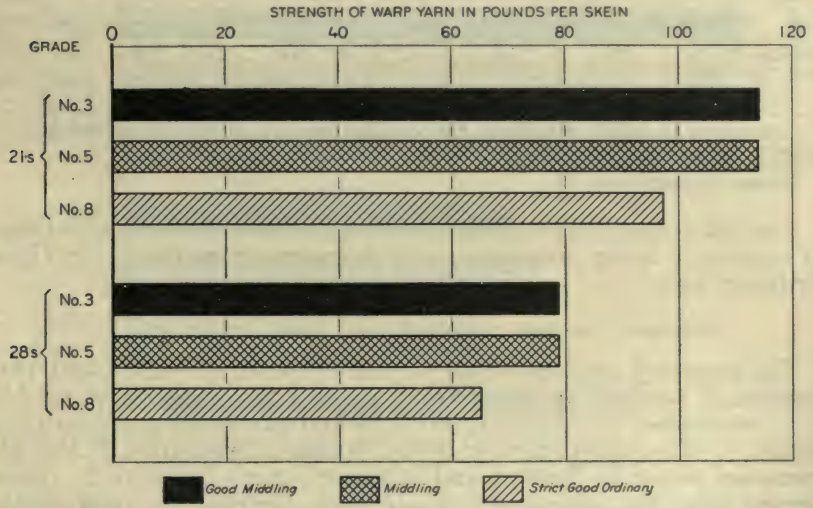


FIGURE 3.—Average strengths of yarn determined by the skein method for three twists of 21s and of 28s warp yarns manufactured from the three selected cottons.

By reference to table 8 and figure 3 it can be seen that the skein strengths of yarns spun from the Good Middling and Middling cottons are approximately equal and much higher than those from the Strict Good Ordinary cotton. The close agreement of the strength of the yarn from Middling to that of the yarns from Good Middling probably may be considered by some to be due to the slightly greater staple length of the Middling bale. However, on a basis of several

hundred bales of American upland cotton, ranging from $\frac{13}{16}$ to $1\frac{1}{4}$ inches, spun in the laboratory at Clemson College, $\frac{1}{32}$-inch increase in staple length has given on the average for 22s yarn an increase of only 2.07 pounds, or 2.15 percent, when based upon the average strength of 22s yarn spun from 1-inch staple. It is obvious, therefore, that other reasons account for the close agreement. The two higher grades produced yarns of excellent strength for cotton of their length, whereas those from the lowest grade are considered fair. These comparisons also are made on a basis of results compiled at the spinning laboratory.

The irregularity of yarn as indicated by the highest, lowest, and average skein-breaking strength and size, and the average deviation and extreme variation of both breaking strength and size, for 21s warp yarns spun with 4.50 twist multiplier, are shown in table 9.

TABLE 9.—*Highest, lowest, and average breaking strengths and sizes and percentage of average deviation and extreme variation of break and size of 21s warp yarns of 4.50 twist multiplier spun from the 3 selected cottons*

| Grade | Breaking strength | | | Yarn size | | | Average deviation [1] | | Extreme variation [2] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Highest | Lowest | Average [3] | Highest | Lowest | Average [3] | Breaking strength | Size of yarn | Breaking strength | Size of yarn |
| | *Pounds* | *Pounds* | *Pounds* | *Count* | *Count* | *Count* | *Percent* | *Percent* | *Percent* | *Percent* |
| Good Middling (No. 3) | 124 | 106 | 114.5 | 22.00 | 20.25 | 20.99 | 3.44 | 1.96 | 15.72 | 8.34 |
| Middling (No. 5) | 129 | 109 | 114.4 | 21.25 | 19.50 | 20.41 | 3.83 | 1.96 | 16.99 | 8.57 |
| Strict Good Ordinary (No. 8) | 106 | 92 | 98.2 | 21.75 | 20.25 | 20.79 | 3.44 | 1.67 | 14.11 | 7.22 |

[1] Calculated by summating all deviations from the mean without regard to sign, then averaging and expressing as a percentage of the mean.
[2] Expressed as a percentage of the mean.
[3] Average of 25 observations.

The differences in irregularity are seen to be small, any advantage of regularity being associated with the yarns from the Strict Good Ordinary bale.

### STRENGTH AND IRREGULARITY OF WARP YARN (SINGLE STRAND)

The corrected average single-strand breaking strengths and percentage of average deviation from 21s and 28s warp yarns of 4.50 twist multiplier are shown in table 10 and presented graphically in figure 4. Frequency curves of the breaking strengths of the 21s yarns are shown in figure 5 and of the 28s yarns in figure 6. These curves show the relative dispersion and skewness for each of the three grades.

The results of the single-strand strength tests, insofar as the relative order of yarn strength of the three cottons is concerned, confirm those of the skein tests. The cottons of the Good Middling and Middling grades gave very nearly equal strengths, whereas the cotton of the lowest grade, Strict Good Ordinary, gave yarns of considerably lower strength. In the case of the 21s yarns, the strength decreased in the order of grade; but for the 28s yarns the intermediate grade furnished the greatest strength, and the lowest grade exhibited the

least strength. It is well to point out that, as sized in the skein, the 28s yarn from the Middling cotton was about 2.5 percent heavier than that from either of the other two grades. Since no correction to specified size was employed in the single yarns, this probably accounts in part for the change in the order of strengths.

TABLE 10.—*Average strength of single-strand 21s and 28s warp yarn of 4.50 twist multipliers, and percentage of average deviation of yarn strength for the 3 selected cottons*

| Grade | Strength of warp yarns [1] | | Average deviation [2] | |
|---|---|---|---|---|
| | 21s | 28s | 21s | 28s |
| | *Ounces* | *Ounces* | *Percent* | *Percent* |
| Good Middling (No. 3) | 16.7 | 10.5 | 8.4 | 9.9 |
| Middling (No. 5) | 16.2 | 11.2 | 8.3 | 10.0 |
| Strict Good Ordinary (No. 8) | 13.7 | 9.5 | 7.6 | 10.5 |

[1] Average based on approximately 775 individual breaks made by Moscrop tester. Average counts of 25 skein observations made on the respective yarns were used as a basis in correcting the data.
[2] Calculated by summating all deviations from the mean without regard to sign, averaging, and expressing as a percentage of the mean.

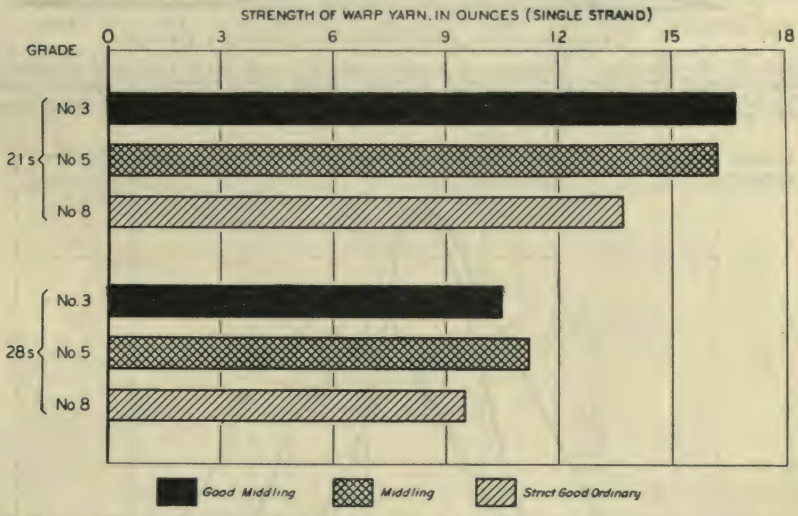


FIGURE 4.—Average strengths of yarn determined by the single-strand Moscrop tester for 28s warp yarns, 4.50 twist multiplier, manufactured from the three selected cottons.

Relatively, the results of the single-strand strength tests for 21s yarns show a slightly greater difference between Good Middling and Middling than do the skein strength tests for these grades (figs. 2 and 4). It may be calculated from the results of both methods of testing upon both counts of yarn that the strength of yarns spun from the Strict Good Ordinary cotton ranges from 10 to 18 percent below that of yarns spun from the cotton of Good Middling grade.

Data having been presented concerning both the skein and the single-strand strength of the yarns, it is of interest to ascertain the

relation existing between these two sets of values. A skein of yarn, as placed on the usual type of strength tester, contains the equivalent of 160 single strands of yarn each 27 inches in length. Theoretically, if all the individual strengths were realized in breaking a skein, the ratio of skein strength to single strand strength would be 160 : 1.

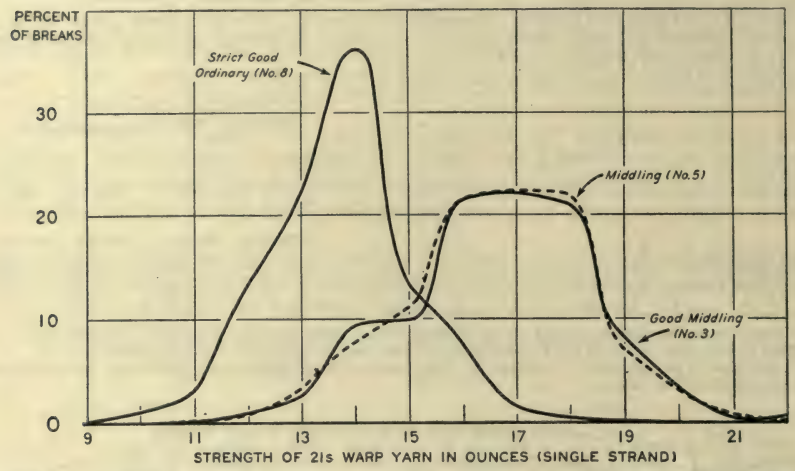


FIGURE 5.—Distribution of strengths of single-strand 21s warp yarn, 4.50 twist multiplier, manufactured from the three selected cottons. Each curve represents approximately 775 observations as recorded by the Moscrop tester. Curves were drawn from original data which were not corrected for size of yarn.

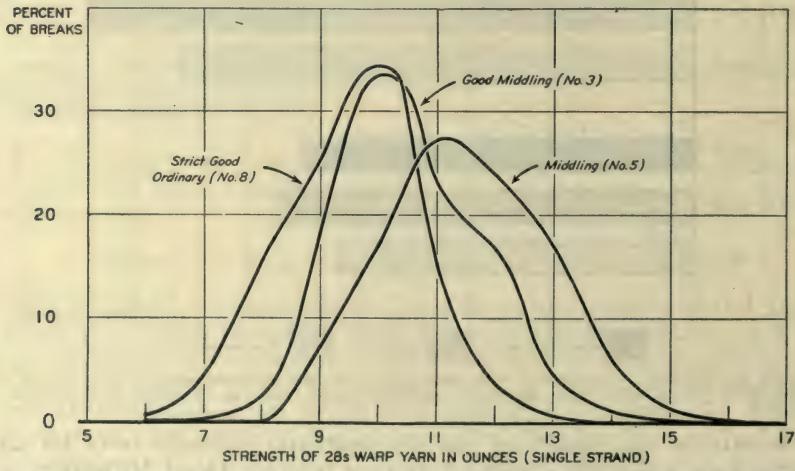


FIGURE 6.—Distribution of strengths of single-strand 28s warp yarn, 4.50 twist multiplier, manufactured from three selected cottons. Each curve represents approximately 775 observations as recorded by the Moscrop tester. Curves were drawn from original data which were not corrected for size of yarn.

This ratio is not actually realized, however, since there is a tendency for the weaker strands to break first, followed by slipping of many of the stronger threads. The ratio of skein strength to single-strand strength for each of the yarns under consideration under the conditions of this test is as shown in table 11.

TABLE 11.—*Ratio of skein strength to single-strand strength*

| Grade | Size of yarn | |
|---|---|---|
| | 21s | 28s |
| Good Middling (No. 3) | 109.6:1 | 121.4:1 |
| Middling (No. 5) | 112.9:1 | 111.8:1 |
| Strict Good Ordinary (No. 8) | 115.1:1 | 110.8:1 |
| Theoretical | 160.0:1 | 160.0:1 |

The results of this test indicate that in the case of 21s yarn a greater proportion of the single-strand strength was realized in the skeins as the grade became lower, whereas for the 28s yarn the reverse was the case.

As in the case of the skein strengths, the 21s yarn from the lowest grade was most regular; but in the case of 28s, this grade gave the most irregular yarn, followed in order by the intermediate and the highest grade.

### COLOR MEASUREMENTS OF RAW STOCK, INTERMEDIATE PRODUCTS, AND FABRICS

Color measurements were made on samples of the cotton from the raw stock, the breaker and finisher laps, and the finished gray and bleached material. The relation of brilliance to grade, as the raw stock passed through the breaker and finisher and then into the gray and bleached cloth, is shown in table 12 and graphically in figure 7.

TABLE 12.—*Brilliance of raw stock, certain intermediate products, and fabrics manufactured from the 3 selected cottons*

| Kind of sample | Brilliance [1] | | |
|---|---|---|---|
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| Raw stock | 8.96 | 8.60 | 7.80 |
| Breaker-picker lap | 8.92 | 8.40 | 7.71 |
| Finisher-picker lap | 9.04 | 8.68 | 7.84 |
| Gray cloth | 8.57 | 8.23 | 7.57 |
| Bleached cloth | 9.80 | 9.70 | 9.40 |

[1] Scale of brilliance extends from 0 (black) to 10 (white).

An examination of the results shows that the brilliance of the raw stock and of products varies with the grade; that is, the higher the grade the greater the brilliance. Generally, the Middling cotton is nearer in brilliance to the Good Middling cotton than to the Strict Good Ordinary. The breaker-lap samples measured a trifle darker than the raw stock, perhaps owing to the fact that the cotton was opened up and the trash loosened. Samples from the finisher-picker lap showed up brighter than those from either the breaker-picker lap or the raw stock, indicating that some of the trash had been removed.

The brilliance measurements reported for the gray and bleached cloths are the result of determinations made on a sample of several layers stretched over a white background, sufficient layers being taken to overcome any effect of the background. It is seen that these figures are in all cases lower than those of the finisher-picker lap. This is owing, no doubt, to the fact that the cotton, although itself a trifle brighter, in the form of cloth caused more shadows than occurred in the finisher-picker lap. The measurements of the gray cloth indicate a difference in brilliance between the Good Middling and Strict Good Ordinary cottons which is comparable to the difference in the raw stock. After bleaching, the brilliance is raised considerably, the low grades being raised relatively more than the high.

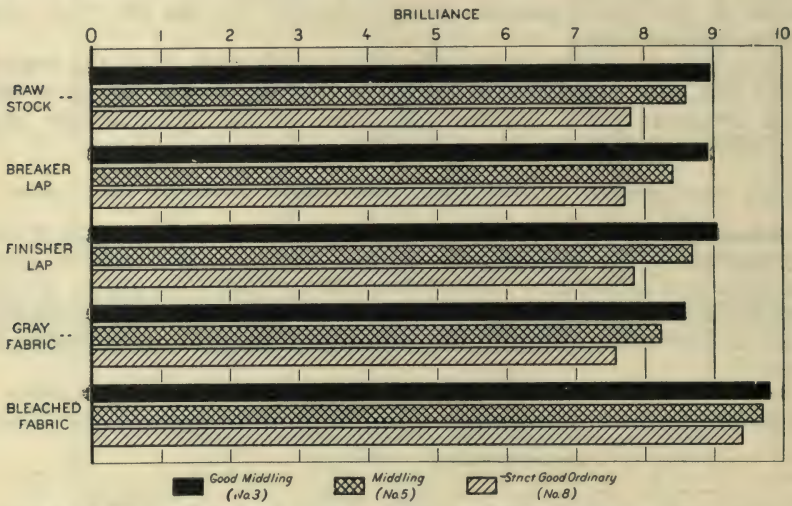


FIGURE 7.—Brilliance of the raw stock of certain intermediate products, of the gray, and of the bleached fabrics manufactured from the three selected cottons.

Spectrophotometric measurements[11] of the reflections at each of seven different wave lengths from the gray and from the bleached cloth are shown in table 13 and presented graphically in figure 8. These measurements of reflection by wave length, when plotted on a logarithmic scale, show results very similar to those obtained from the brilliance measurements. Brilliance is measured in units equal to the eye and bears a definite relation to percentage of light reflected. It has been thought by some to bear a logarithmic relationship and, although this does not agree precisely with the Munsell scale, it is used in figure 8 in order to show the general relationship. The two sets of figures cannot be precisely adjusted, since the illumination under which they were measured and the thickness of the material differed for the two measurements. The grades maintain approximately relative positions with respect to relative reflection of the wave lengths measured. The reflections of the gray cloths, which are a light dull yellow in color, were less from the blue end of the spectrum than from the red end. The

[11] These measurements were made on a Keuffel & Esser color analyzer through the courtesy of Carl W. Keuffel.

bleached cloths gave a much higher relative reflection throughout the range of wave lengths, and the reflections did not differ appreciably for the different wave lengths. This is a fact which corresponds to their whiteness, since the higher and flatter the curve, the whiter the color.

TABLE 13.—*Reflection at different wave lengths of gray and of bleached cloth manufactured from the 3 selected cottons*

| Wave length in mμ | Reflection [1] | | | | | |
|---|---|---|---|---|---|---|
| | Gray | | | Bleached | | |
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| 440 | 0.52 | 0.52 | 0.43 | 0.84 | 0.80 | 0.76 |
| 480 | .55 | .54 | .43 | .87 | .83 | .82 |
| 520 | .60 | .57 | .47 | .89 | .86 | .83 |
| 560 | .65 | .60 | .49 | .89 | .85 | .83 |
| 600 | .67 | .63 | .52 | .89 | .84 | .84 |
| 640 | .70 | .66 | .53 | .90 | .86 | .85 |
| 680 | .74 | .67 | .56 | .91 | .87 | .86 |

[1] Results expressed relative to the reflection of magnesium carbonate.

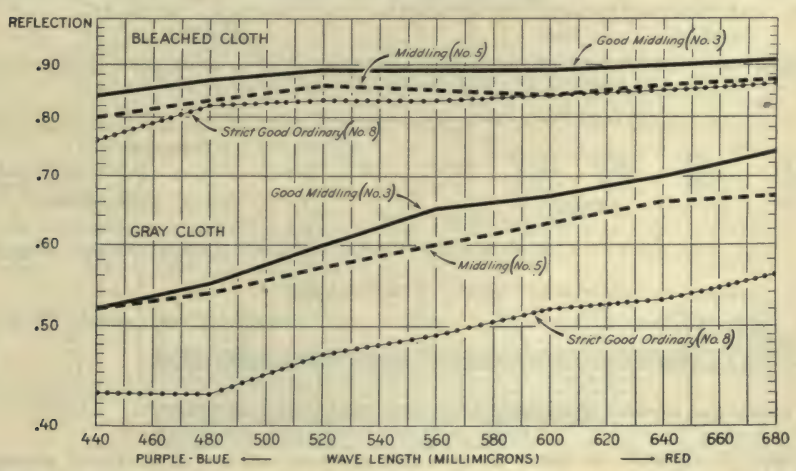


FIGURE 8.—Relative spectral reflectance of gray and bleached fabrics manufactured from the three selected cottons.

### FOREIGN MATTER IN THE FABRICS

The gray fabrics from the different grades differed noticeably in their appearance to the eye in color, luster, and amount of foreign matter present on the surface. The gray fabric prepared from the Good Middling cotton was a bright, creamy white, with a very small quantity of fine pin trash. That prepared from the Middling cotton had a slightly darker, grayish-yellow cast, much duller than that made from the Good Middling cotton, and the trash was a little more noticeable. The gray fabric prepared from the Strict Good Ordinary cotton had a still darker, grayish-yellow color and considerably more pin trash than that from the Middling cotton.

That a quantitative relationship between grade and surface foreign matter might be established for the gray fabrics, the average number of particles of trash in a surface area of 9 square inches was determined. This was done by placing a mat with a 3-inch square opening on the smooth surface of the cloth and counting the particles in each of 20 such areas. The average number of particles of foreign matter observed per 3-inch square on the gray from each of the three grades was as follows:

| | *Average number of particles per 3 by 3-inch square* |
|---|---|
| Good Middling (No. 3) | 7.2 |
| Middling (No. 5) | 10.7 |
| Strict Good Ordinary (No. 8) | 23.9 |

The bleached samples from each of the three grades differed little as to pin trash, practically all of this material having been removed in the finishing process. When the finished fabrics were placed side by side, however, a difference in color and luster between the Good Middling and Strict Good Ordinary cotton was easily discernible. Differences between the fabrics from the Middling cotton and those from either of the other grades were much less noticeable.

### TENSILE STRENGTH OF THE FABRICS

The averages for the number of threads per inch both warpwise and fillingwise for the gray and bleached fabrics are shown in table 14, and the corresponding strengths are shown in table 15.

TABLE 14.—*Construction of gray and bleached fabrics manufactured from the 3 selected cottons*

| Grade | Threads per inch [1] | | | |
|---|---|---|---|---|
| | Gray | | Bleached | |
| | Warpwise | Fillingwise | Warpwise | Fillingwise |
| | *Number* | *Number* | *Number* | *Number* |
| Good Middling (No. 3) | 65 | 64 | 72 | 62 |
| Middling (No. 5) | 65 | 63 | 72 | 63 |
| Strict Good Ordinary (No. 8) | 65 | 65 | 71 | 60 |

[1] Each average represents 6 observations.

TABLE 15.—*Tensile strength of gray and bleached fabrics from the 3 selected cottons*

| Grade | Tensile strength of 1-inch strip [1] | | | |
|---|---|---|---|---|
| | Gray | | Bleached | |
| | Warpwise | Fillingwise | Warpwise | Fillingwise |
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Good Middling (No. 3) | 63.0 | 50.3 | 63.8 | 41.4 |
| Middling (No. 5) | 60.6 | 49.0 | 65.2 | 38.8 |
| Strict Good Ordinary (No. 8) | 52.1 | 43.8 | 51.5 | 31.1 |

[1] Each average represents 15 observations.

It may be seen from table 14 that the number of warp threads per inch of the finished sheetings was considerably higher than that of the gray whereas the number of filling threads per inch was more nearly the same. This change in construction is explained by the fact that, in the finishing process, the fabrics shrank on an average of 10 inches in width, from 72 to 62 inches, the length changing but slightly, approximately 3 percent..

Table 16 and figure 9 show the figures of table 15 converted to a comparable basis, namely, a construction of 64 by 64 threads per inch. The corrected tensile strength of the fabrics in all cases, except that of the bleached fabric tested warpwise, decreased with the grade. In the case of the exception noted, the fabric from the Good Middling had a somewhat lower strength than that from the Middling cotton but a considerably higher strength than that from the Strict Good Ordinary cotton. In all cases the fabrics from Middling showed a strength much closer to that of fabrics from Good Middling than to that of fabrics from Strict Good Ordinary.

TABLE 16.—*Corrected tensile strength of gray and bleached fabrics manufactured from the 3 selected cottons*

| Grade | Tensile strength corrected for 64 by 64 construction [1] | | | |
|---|---|---|---|---|
| | Gray | | Bleached | |
| | Warpwise | Filling-wise | Warpwise | Filling-wise |
| | *Pounds* | *Pounds* | *Pounds* | *Pounds* |
| Good Middling (No. 3) | 62.0 | 50.3 | 56.7 | 42.7 |
| Middling (No. 5) | 59.7 | 49.8 | 58.0 | 39.4 |
| Strict Good Ordinary (No. 8) | 51.3 | 43.1 | 46.4 | 33.2 |

[1] Based on data shown in tables 14 and 15, no allowance being made for the fabric assistance.

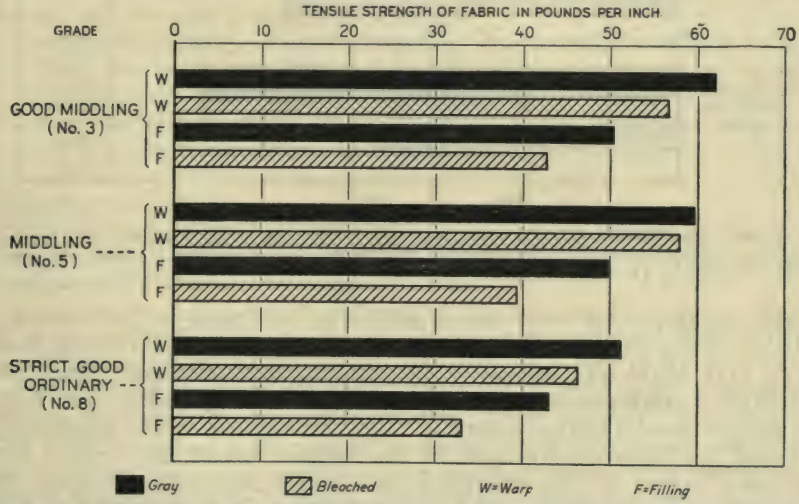


FIGURE 9.—Average corrected tensile strength determined by the strip method for the gray and for the bleached fabrics manufactured from the three selected cottons. (Each bar represents the average of 15 observations.)

On an average the corrected strength of the bleached fabric, as determined by the strip method, decreases 6.9 percent warpwise and 19.5 percent fillingwise.

### BURSTING STRENGTH OF THE FABRICS

The average bursting strength per square inch for the gray and bleached fabrics from each of the three grades is shown in table 17 and figure 10.

TABLE 17.—*Average bursting strength of gray and bleached fabrics manufactured from the 3 selected cottons*

| Grade | Bursting strength per square inch per fabric [1] | |
|---|---|---|
| | Gray | Bleached |
| | *Pounds* | *Pounds* |
| Good Middling (No. 3) | 153.7 | 106.0 |
| Middling (No. 5) | 154.7 | 104.3 |
| Strict Good Ordinary (No. 8) | 126.7 | 79.0 |

[1] Each average represents 15 tests made on a Mullen tester.

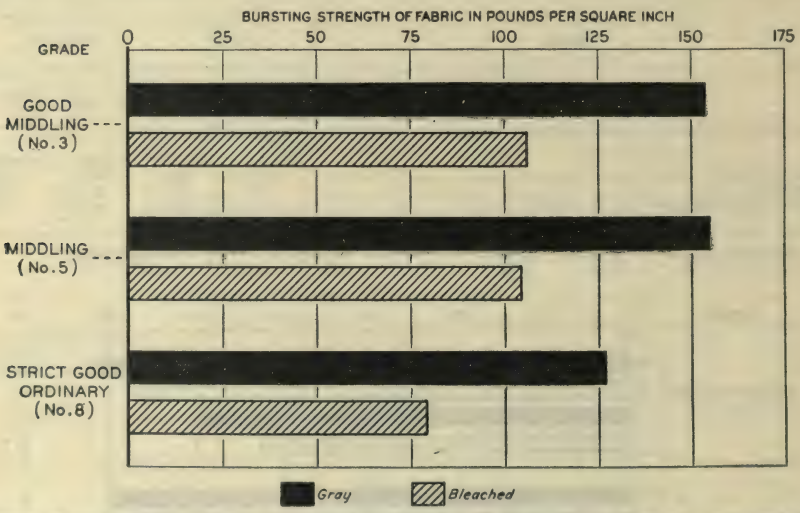


FIGURE 10.—Average bursting strength determined by a Mullen tester for the gray and for the bleached fabrics manufactured from the three selected cottons. (Each bar represents average of 15 observations.)

The results show very little difference in strength between the fabrics, either gray or bleached, manufactured from the Good Middling and Middling cottons. The fabrics manufactured from the two higher grades were much stronger than those manufactured from the Strict Good Ordinary cotton. The finishing process apparently lowered the bursting strength of the fabrics about one third. For the gray fabric, it was observed that in the majority of cases the filling threads broke as the fabric burst, whereas in the finished fabrics the warp threads broke in every instance.

## CONCLUSIONS

The more important results obtained in the manufacture of the three selected cottons into sheeting and from certain studies made on their fibers, intermediate products, yarns, and fabrics under the conditions, as described, are listed as follows:

As compared with previous results obtained from cottons of the same grades and similar staple, the percentage of waste removed from the Good Middling and Strict Good Ordinary cottons was about average. On the other hand, the waste from the Middling cotton was somewhat lower than would be expected for this grade.

The length of fibers differed slightly for the three bales, that for the Middling bale being a trifle longer than that for the other two. On a basis of previous results, however, the small differences in length of raw cotton would not be expected to account for the relatively higher strength of the products from this bale.

The length of fibers from the three bales of cotton did not change appreciably in the course of the manufacturing processes.

The number of ends breaking per 100 spindles per hour increased as the grade became lower and was more than double for the Strict Good Ordinary than for the Good Middling cotton.

Both skein and single-strand tests on 21s and 28s warp yarns showed the Good Middling and Middling cottons to have approximately equal strength. The Strict Good Ordinary cotton gave yarns from 10 to 18 percent weaker by both skein and single-strand tests than either of the other grades of this test.

In both the skein and the single-strand strength tests on 21s warp yarn, the Strict Good Ordinary cotton showed slightly more regularity than for either of the other two grades. This regularity was correlated with regularity of size in the skein tests. In the single-strand tests of 28s warp yarn, the regularity decreased with the grade.

The brilliance of the cottons decreased as the grade became lower. The cottons of the three grades retained their relative positions with respect to brilliance throughout the manufacturing processes, but the spread became smaller after bleaching.

Spectrophotometric measurements of the reflection of light from the gray and bleached fabrics for each of the three grades agreed, in general, with the brilliance measurements. The gray cloth, because of its yellow color, gave a greater reflection toward the red end of the spectrum, while the bleached cloth, on the other hand, gave more nearly the same relative reflection throughout the range of wave lengths used.

The average number of fine particles of foreign matter in the gray cloth increased greatly as the grade became lower, but they largely disappeared after the finishing process.

A reduction in the width of the gray fabric from 72 inches to about 62 inches occurred as a result of the finishing process, whereas the length increased approximately 3 percent.

The corrected tensile strength of strips of gray and of bleached fabrics decreased as the grade became lower except in one case in which the bleached fabric from the Middling cotton tested warpwise was stronger than the corresponding fabric from the Good Middling. Relatively, the tensile strength of the fabric from the Middling cotton was much nearer that from the Good Middling than that of the

Strict Good Ordinary cotton. On an average the corrected strength of the bleached fabric as determined by the strip method decreases 6.9 percent warpwise and 19.5 percent fillingwise over that of the gray fabric.

The bursting strength of the gray and of the bleached fabrics from the Good Middling and Middling cotton was about equal and was much higher than that of the gray and of the bleached fabric made from the Strict Good Ordinary cotton. Bleaching resulted in a reduction of approximately 33 percent in bursting strength per square inch for the fabrics manufactured from each of the three grades.

Discrepancies between observation and expectation, noted in a few instances particularly in the case of the Middling bale, are not surprising when it is considered that many of the important fiber properties which are involved in cotton quality are beyond the province of the grade factors and the grade designations. These fiber properties, moreover, may vary greatly for a given grade and it must be evident that only insofar as they collectively assume mean values for a given bale can that bale be said to represent the particular grade category.

## SERVICEABILITY OF THE FABRICS

By MARGARET B. HAYS and RUTH E. ELMQUIST

In connection with investigations of various aspects of cotton utilization, the Department is attempting to evaluate different grades and varieties of cotton in terms of their relative usefulness in finished fabrics. In this study, sheetings made from American upland cotton, selected to represent the Good Middling, Middling, and Strict Good Ordinary grades, were submitted to laboratory and wearing tests. For details of the construction and manufacture of these fabrics see page 6.

No investigations of the durability of known grades of cotton when woven into fabrics are reported in the literature although a few studies have been made of the reaction to laundering of fabrics made of cotton of unknown grade and staple. The effect of repeated washing on some damasks, sheetings, and shirtings was published by Griffith and her coworkers (*26*) and the durability of ginghams and five white cotton fabrics when subjected to laundering was reported by Ginter and Rhodes (*24*). Furry and Edgar (*21*, *22*) analyzed 109 commercial brands of sheeting and the deterioration of 5 of these due to laundering was studied by Griffith and Edgar (*25*). MacDonald (*36*) reported an investigation by Consumers' Research, Inc., in cooperation with the New England Laundries, on the loss due to washing and to washing plus ironing of 10 brands of sheets having the largest volume of sales in 3 Boston stores. A preliminary report (*5*) has been published by the Cotton Textile Institute of a study begun in 1928, in which 24 mill brands of sheeting were subjected to actual service in the Grasslands Hospital in Westchester County, N.Y. Carpenter [12] and Miller [13] have compared the deterioration of sheets washed at a

[12] CARPENTER, C. E. COMPARATIVE ANALYSIS OF NINE BRANDS OF SHEETS. 1928. [Unpublished master's thesis. Copy on file Dept. Home Economics, Univ. Chicago, Chicago.]

[13] MILLER, E. M. AN ANALYTICAL STUDY OF COMMERCIAL BRANDS OF SHEETS. 1929. [Unpublished master's thesis. Copy on file Dept. Home Economics, Univ. Chicago, Chicago.]

commercial laundry and in the laboratory. The effect of commercial laundering on 24 brands of sheets was also investigated by Millard (*1*) in a study in which they were washed 160 times without wear. The grade and staple of the raw cotton used in the fabrics was not taken into consideration by these investigators and they did not follow the chemical changes produced by laundering. In the present study, changes in the chemical, as well as the physical characteristics of the sheetings were investigated.

### WEARING TEST

No laboratory test has yet been devised which approximates actual service conditions. Therefore, in order to study the reaction of these grades of cotton to wear, the finished sheets were put into service in a Washington hotel.[14] This hotel maintains its own laundry and the staff cooperated to control the conditions both of the use and the laundering of the sheets. Variables in laundering procedure due to changes in personnel during the 2½ years the test was in progress, were not significant.

Thirty sheets of each of the three grades of cotton were marked with an individual identifying number. Before being used, they were given 2 hot rinses and 1 cold rinse to remove the finishing material. After the excess of water was removed by extraction, they were ironed, dried thoroughly, and put into service on a transient-guest floor of the hotel. The beds had no rough edges on the frames or springs which would cause undue wear.

Two sheets were used per bed each day, the wide hem always being placed at the head of the bed. It is assumed that over a long period each was used an equal number of times as the top and as the bottom sheet, and that the wear was uniform at any testing period. All sheets, except those removed for testing, were used as long as serviceable. According to the hotel routine, those laundered one day were not put on the beds until the next day, but were stored overnight to permit thorough drying. Approximately half of the lot was used each day so all the sheets were in almost continuous service even though some of the beds were not occupied every night.

Each morning the used sheets were collected and sent to the hotel laundry, where they were held until a worker from the Bureau of Home Economics arrived to watch the washing process. A record was kept of the time required for each suds, rinse, extraction, and ironing for every day any of the sheets were washed. Any variation in method was noted on this record.

For the first 4 months the washing procedure was a 15-minute suds, which was started cold and into which the steam was turned after a few minutes' running, 2 hot rinses, each 3 to 5 minutes, and 2 cold rinses, each 3 minutes long. Due to personnel changes in the laundry the method used for the remainder of the time was a cold breakdown of 6 minutes, a hot suds (approximately 160° F.) of 10 minutes, sometimes another suds, depending on the load, 3 hot rinses (120° to 130°) of 3 to 6 minutes each, and 1 or 2 cold rinses (90° to 100°), each 3 to 5 minutes. As it was not possible to control the washing

[14] Acknowledgment is made to Mary Lindsley, manager of the Dodge Hotel, Washington, D.C., for extending the facilities of the hotel for this study, and to Fanny Jeffrey, of the hotel staff, for cooperation in supervising the service and the laundering of the sheets.

temperature automatically, only approximate temperatures are reported.

The first year, a soap solution was used of such concentration that the wheel contained one fourth of a pound of soap chips and one eighth of a pound of soda in 8 to 10 gallons of water. The remainder of the time soap chips alone were used. In accordance with the regular hotel practice, no bleaching was done and bluing was added to the last cold rinse only during a month each spring.

After rinsing, the sheets were extracted 7 to 12 minutes and then ironed, selvage to selvage, through a 4-roller mangle heated with steam at 65 to 70 pounds pressure. The sheets were always folded by hand.

The daily record of the identifying number of each sheet washed was obtained when it was folded. Thus it was possible to determine exactly how many times a given sheet was laundered. A chart was kept for each sheet, breaks being recorded thereon as they occurred. The area, kind of break, and number of washes at which each break appeared were recorded. The sheets were then repaired in the hotel mending room and returned to service.

Ordinary stains were removed by the regular washing or by soaking in the soap tank overnight and then rewashing. This and any other necessary stain-removal treatment was recorded. Sheets for testing were selected at random and of these only two had ever been placed in the soap tank to remove stains.

### LABORATORY TESTS [15]

One sheet of each grade of cotton was removed at intervals (table 18) and tested for weight, thread count, thickness, and breaking and bursting strength. All samples were conditioned at least 4 hours before testing in a room maintained at 70° F. and 65 percent relative humidity. Fluidity, copper number, and methylene blue absorption determinations were also made at the same test periods.

#### SAMPLING

The area, 22 inches wide and 71 inches long, most probably occupied by the body as shown in the diagram given by O'Brien and Steele (*44*) was used for sampling (fig. 11). Breaking-strength determinations were made with strips taken at the places of probable maximum wear, symmetrical to the center line and selected so that no warp or filling threads were duplicated. The sections B, C, and D each supplied 5 warp and 5 filling strips and 3 bursting-strength samples. In addition, the A, B, and C sections each furnished 1 and the D section 2 samples for determining the weight per square yard of the fabric. The middle fold was tested for breaking strength in four places both warpwise and fillingwise. Thickness and thread count were determined on the pieces used for the weight determinations. Sections A, B, C, and D were sampled for the fluidity and copper-number determinations. A composite sample of all four sections was taken for the methylene blue absorptions. The remainder of the sheet was used in the ironing study (see pp. 48 to 64).

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[15] The assistance rendered by Jeanne D. Guerin, of the Bureau staff, both at the hotel and in the laboratory, is gratefully acknowledged. Doris M. Buchanan, formerly of the Bureau staff, assisted with the chemical determinations.

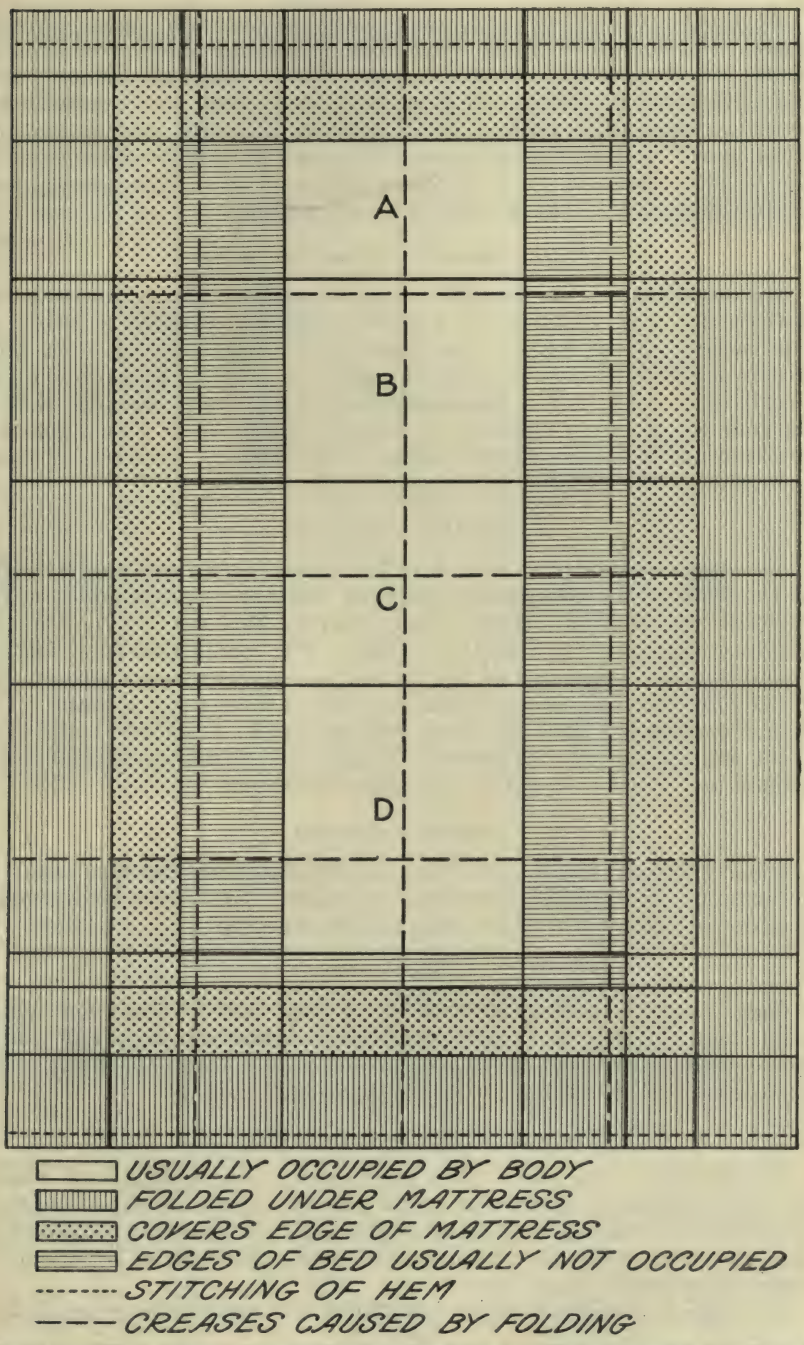


FIGURE 11.—Plan of layout for sampling laundered sheets. The part occupied by the body was tested. Section A is ordinarily occupied by the pillow, section B by the shoulders and back, section C by the hips, and section D by the legs and feet.

At the beginning all tests were made on the new fabric of each grade. In order to study the effect of aging only, two control sheets of each grade of cotton were stored when the others were put into service. Every time a laundered sheet was removed for testing, breaking strength and bursting strength determinations were made on the stored fabric. The samples from these control sheets were selected to be representative of the entire sheet, none being taken closer than 12 inches to the selvage.

### WEIGHT, THREAD COUNT, AND THICKNESS

In determining the weight, 2-inch squares were stamped out with a die and weighed on a torsion balance reading directly in ounces per square yard. The number of threads in an inch both warpwise and fillingwise was determined with a thread-counting micrometer. Thickness was measured on the same samples with a micrometer gage graduated to read to 0.001 inch, which exerted constant pressure on a given area of the fabric. In each of these tests, the average of five readings was reported.

### BREAKING STRENGTH

The strip method was used for determining the breaking strength of the sheets. In accordance with the method recommended by the Federal Specifications Board (*53*), samples were cut 1¼ by 6 inches and raveled down to exactly 1 inch. The pendulum-type testing machine with a capacity of 150 to 300 pounds was motor driven, the lower jaw traveling down at the rate of 12 inches per minute. The distance between the top and bottom jaws, 3 inches wide both front and back, was 3 inches. Warp and filling specimens were broken and in each case 15 values were averaged.

### BURSTING STRENGTH

The steel-ball attachment for the testing machine was used to determine the bursting strength. Samples were cut 4 by 4 inches and the average of nine determinations reported.

### SHRINKAGE

Each sheet was measured before going into service and again after being removed. The length was measured in three places and width in five, to the nearest one sixteenth of an inch. The shrinkage was calculated from these measurements.

### FLUIDITY IN CUPRAMMONIUM SOLUTION

The fluidity (viscosity) tests were made with solutions of cotton in cuprammonium hydroxide at 25° C. by means of capillary-tube viscometers. Since the details of the method used were developed in connection with the ironing study, the description of the procedure is given on page 53.

The fluidity values were calculated in centimeter-gram-second units by the equation $F=\frac{q}{C(P-p)}$ where $F$ equals the fluidity, $C$ the constant of the instrument, $q$ the rate of flow, and the quantity $(P-p)$ the average pressure causing flow. The value of $C$ is given

by the expression $\frac{\pi g d^4}{128 L}$, where $g$ is the acceleration of gravity, $d$ is the internal diameter of the capillary tube and $L$, the length of the capillary. The quantities $d$ and $L$ were 0.1136 and 3.23 centimeters, respectively, for this study. $\frac{q}{P-p}$ is obtained from flow pressure graphs (fig. 17) where the pressure head, $P$, is plotted as abscissa and the rate of flow, $q$, as ordinate. The intercept on the pressure axis gives the yield value, $p$.

#### COPPER NUMBER

The method adopted was the same as that described in the ironing study (p. 56). Analyses were made with 1.5 grams of the finely divided conditioned material and the results are recorded in grams of copper reduced per 100 grams of dry cotton.

#### ABSORPTION OF METHYLENE BLUE

The titrimetric method of Clibbens and Geake (*14*) was used, in which the disintegrated material was treated with a buffered methylene blue solution of pH 7. The most worn sheetings absorbed so much methylene blue that 0.3-gram samples were substituted for the 2.5-gram quantities recommended by Clibbens and Geake (*14*). Since methylene blue absorption values may be greatly influenced by the presence of traces of alkali or soap, the materials, previous to the absorption measurements, were steeped for 1 hour in $\frac{N}{10}$ sulphuric acid and then rinsed and steeped in distilled water until the washings were neutral. The absorption is expressed in millimols of methylene blue per 100 grams of dry cotton.

#### RESULTS

The change in weight of the sheets after the first wash was not appreciable, but there was a gradual loss in weight with service, as shown in table 18. Grade No. 8 (Strict Good Ordinary) was always slightly lighter than grade No. 3 (Good Middling) or grade No. 5 (Middling), and the loss in weight for grade No. 8 at 210 washes was the same as for grades Nos. 3 and 5 after 240 washes. This seems to indicate that after a loss of 20 percent (0.8 ounce, approximately) sheets are no longer serviceable. These three cottons were all made into sheets of medium weight, so no generalization can be made as to what might apply for lightweight or heavyweight sheetings. In the order of increasing weight, the grades ranked Strict Good Ordinary, Middling, and Good Middling.

The values for thread count are also given in table 18. The number of warp threads per inch decreased, while the number of filling threads increased with washing. This change was expected, as the sheets were shrinking in length and stretching in width. All the fabrics showed a trend toward the same number of threads in both warp and filling directions after 125 washes. As shown in this table thickness increased with the first washing due to shrinkage. In all cases the variation in thickness was slight and of the same order as the error in measuring.

TABLE 18.—*Thread count, weight, and thickness, after repeated launderings and wear, for sheetings made from the 3 selected cottons*

| Grade of cotton | Test period (times laundered) | Threads per inch | | Weight per square yard | Thickness |
|---|---|---|---|---|---|
| | | Warp | Filling | | |
| | *Number* | *Number* | *Number* | *Ounces* | *Inches* |
| Good Middling (No. 3) | [1] 0 | [1] 71 | [1] 63 | [1] 4.07 | [1] 0.009 |
| | 1 | 73 | 63 | 4.10 | .011 |
| | 75 | 70 | 65 | 4.02 | .011 |
| | 125 | 69 | 65 | 3.78 | .010 |
| | 150 | 68 | 67 | 3.80 | .010 |
| | 175 | 70 | 68 | 3.78 | .010 |
| | 200 | 70 | 68 | 3.76 | .010 |
| | 225 | 70 | 69 | 3.50 | .010 |
| | 240 | 70 | 67 | 3.34 | .010 |
| Middling (No. 5) | [1] 0 | [1] 72 | [1] 62 | [1] 4.01 | [1] .009 |
| | 1 | 72 | 63 | 3.98 | .011 |
| | 75 | 70 | 67 | 4.00 | .011 |
| | 125 | 70 | 67 | 3.76 | .010 |
| | 150 | 69 | 66 | 3.64 | .010 |
| | 175 | 68 | 67 | 3.60 | .010 |
| | 200 | 69 | 68 | 3.74 | .010 |
| | 225 | 68 | 69 | 3.26 | .009 |
| | 240 | 69 | 70 | 3.44 | .009 |
| Strict Good Ordinary (No. 8) | [1] 0 | [1] 71 | [1] 61 | [1] 3.89 | [1] .009 |
| | 1 | 72 | 63 | 3.90 | .011 |
| | 75 | 68 | 65 | 3.70 | .011 |
| | 125 | 68 | 66 | 3.44 | .010 |
| | 150 | 67 | 64 | 3.50 | .010 |
| | 165 | 69 | 65 | 3.38 | .009 |
| | 175 | 68 | 66 | 3.34 | .010 |
| | 200 | 68 | 66 | 3.24 | .010 |
| | 210 | 68 | 65 | 3.12 | .010 |

[1] Average of 2 control sheets.

The average breaking strengths of the B, C, and D sections and middle fold of the sheets after various periods of wear are shown in table 19 and figure 12. In all three grades the breaking strength of the B section was always the lowest, while the C and D sections were of the same order. Contrary to the results of an analysis of sheets previously used at the hotel (*44*), the strength of the middle fold was no lower than that of the section from which it was taken. The Strict Good Ordinary sheets had a lower initial breaking strength, but the general downward trend was the same for all three grades.

The loss in breaking strength as compared with a new sheet of each grade is given in table 20 and plotted in figure 13. The greater loss in the breaking strength of the warp up to 75 washes is probably due to the loss of sizing. A comparison of the loss in strength of sheets washed once and 75 times shows that approximately half the loss in the warp during this interval took place in the first wash as did almost all the loss in the filling.

A laundered sheet would appear relatively stronger as a result of shrinkage. For comparison, therefore, the average breaking strengths were calculated for a 64 by 64 fabric, which was the gray specification (table 21). The index value, the average breaking strength in pounds divided by the average thread count, was computed for both the warp and filling directions (table 22 and fig 14). The strength-weight factor, the sum of the warp and filling breaking strength in pounds divided by the weight per square yard in ounces,

is plotted in figure 15. By both methods of comparison, grade No. 5 is higher than 3, which in turn is above 8, except for the inversion of 3 and 5 at 125 and 225 washes.

TABLE 19.—*Breaking strength of various sections of sheetings made from the 3 selected cottons tested after repeated launderings and wear*

| Grade of cotton | Test period (times laundered) | Breaking strength [1] | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Warp | | | | | Filling | | | | |
| | | Section | | | Average | Middle fold | Section | | | Average | Middle fold |
| | | B | C | D | | | B | C | D | | |
| | *No.* | *Lb.* | *Lb* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| Good Middling (No. 3) | [2] 0 | [2] 61.7 | [2] 61.6 | [2] 63.8 | [2] 62.4 | ------- | [2] 41.5 | [2] 42.5 | [2] 42.1 | [2] 42.0 | ------- |
| | 1 | 49.4 | 52.8 | 53.7 | 52.0 | ------- | 33.3 | 32.8 | 33.4 | 33.2 | ------- |
| | 75 | 38.1 | 48.7 | 48.7 | 45.2 | 45.9 | 30.6 | 32.5 | 34.5 | 32.5 | 35.1 |
| | 125 | 35.6 | 40.3 | 36.6 | 37.5 | 34.8 | 20.1 | 24.9 | 26.2 | 23.7 | 22.2 |
| | 150 | 29.7 | 32.5 | 32.1 | 31.4 | 32.3 | 16.2 | 18.3 | 18.6 | 17.7 | 20.3 |
| | 175 | 26.2 | 29.0 | 29.7 | 28.3 | 28.3 | 12.2 | 17.0 | 15.6 | 14.9 | 15.8 |
| | 200 | 20.8 | 27.6 | 25.9 | 24.8 | 27.1 | 8.3 | 14.2 | 13.4 | 12.0 | 12.5 |
| | 225 | 17.9 | 26.4 | 26.2 | 23.5 | 23.0 | 5.6 | 13.5 | 10.8 | 10.0 | 9.6 |
| | 240 | 14.1 | 19.1 | 22.8 | 18.7 | 19.3 | 3.4 | 8.6 | 6.6 | 6.2 | 5.1 |
| Middling (No. 5) | [2] 0 | [2] 61.2 | [2] 59.2 | [2] 61.5 | [2] 60.6 | ------- | [2] 37.9 | [2] 38.7 | [2] 39.2 | [2] 38.6 | ------- |
| | 1 | 52.4 | 49.4 | 54.5 | 52.1 | ------- | 32.0 | 33.3 | 32.0 | 32.4 | ------- |
| | 75 | 45.1 | 47.0 | 46.2 | 46.1 | 49.3 | 30.2 | 34.5 | 33.5 | 32.7 | 32.8 |
| | 125 | 31.4 | 37.7 | 35.7 | 34.9 | 32.9 | 22.5 | 22.5 | 25.7 | 23.6 | 22.0 |
| | 150 | 28.9 | 36.8 | 36.4 | 34.0 | 33.7 | 16.9 | 17.6 | 20.2 | 18.2 | 18.8 |
| | 175 | 27.2 | 28.8 | 31.2 | 29.1 | 32.0 | 12.4 | 15.9 | 16.6 | 15.0 | 15.5 |
| | 200 | 22.5 | 28.8 | 28.3 | 26.5 | 27.3 | 10.7 | 13.9 | 13.2 | 12.6 | 10.3 |
| | 225 | 16.5 | 23.9 | 23.6 | 21.3 | 21.4 | 4.2 | 10.4 | 9.1 | 7.9 | 8.6 |
| | 240 | 17.1 | 24.2 | 21.5 | 20.9 | 20.5 | 4.9 | 8.9 | 6.1 | 6.6 | 6.5 |
| Strict Good Ordinary (No. 8) | [2] 0 | [2] 49.5 | [2] 50.4 | [2] 50.9 | [2] 50.3 | ------- | [2] 29.1 | [2] 30.4 | [2] 30.3 | [2] 29.9 | ------- |
| | 1 | 43.3 | 45.9 | 45.4 | 44.9 | ------- | 28.8 | 29.6 | 27.9 | 28.8 | ------- |
| | 75 | 39.2 | 39.8 | 38.8 | 39.3 | 38.9 | 27.4 | 27.6 | 28.9 | 28.0 | 26.5 |
| | 125 | 27.9 | 30.1 | 32.0 | 30.0 | 29.9 | 13.8 | 19.3 | 18.6 | 17.2 | 20.1 |
| | 150 | 24.4 | 28.6 | 28.1 | 27.0 | 28.2 | 13.4 | 15.9 | 15.7 | 15.0 | 15.6 |
| | 165 | 22.8 | 25.7 | 24.9 | 24.5 | 21.4 | 9.0 | 13.3 | 12.1 | 11.5 | 12.8 |
| | 175 | 20.6 | 25.3 | 25.1 | 23.7 | 24.0 | 7.9 | 13.5 | 12.9 | 11.4 | 12.8 |
| | 200 | 14.3 | 18.1 | 17.7 | 16.7 | 15.0 | 3.3 | 7.4 | 8.8 | 6.5 | 8.0 |
| | 210 | 15.1 | 19.0 | 17.6 | 17.2 | 19.4 | 5.5 | 7.8 | 7.8 | 7.0 | 7.4 |

[1] Strip method.
[2] Average of controls for 8 test periods.

TABLE 20.—*Loss in breaking strength of sheetings made from the 3 selected cottons tested after different intervals of service*

| Test period (times laundered) | [1]Loss in breaking strength | | | | | |
|---|---|---|---|---|---|---|
| | Good Middling (No. 3) | | Middling (No. 5) | | Strict Good Ordinary (No. 8) | |
| | Warp | Filling | Warp | Filling | Warp | Filling |
| | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| 1 | 16.7 | 20.9 | 14.0 | 16.1 | 10.8 | 3.7 |
| 75 | 27.6 | 22.6 | 23.9 | 15.3 | 21.9 | 6.4 |
| 125 | 39.9 | 43.6 | 42.4 | 38.9 | 40.4 | 42.5 |
| 150 | 49.8 | 57.9 | 43.9 | 52.8 | 46.3 | 50.8 |
| 165 | ------- | ------- | ------- | ------- | 51.4 | 61.6 |
| 175 | 54.7 | 64.5 | 51.9 | 61.2 | 52.9 | 61.9 |
| 200 | 60.3 | 71.5 | 56.3 | 67.4 | 66.8 | 78.3 |
| 210 | ------- | ------- | ------- | ------- | 65.9 | 76.7 |
| 225 | 62.5 | 76.2 | 64.8 | 79.6 | ------- | ------- |
| 240 | 70.2 | 85.4 | 65.4 | 82.9 | ------- | ------- |

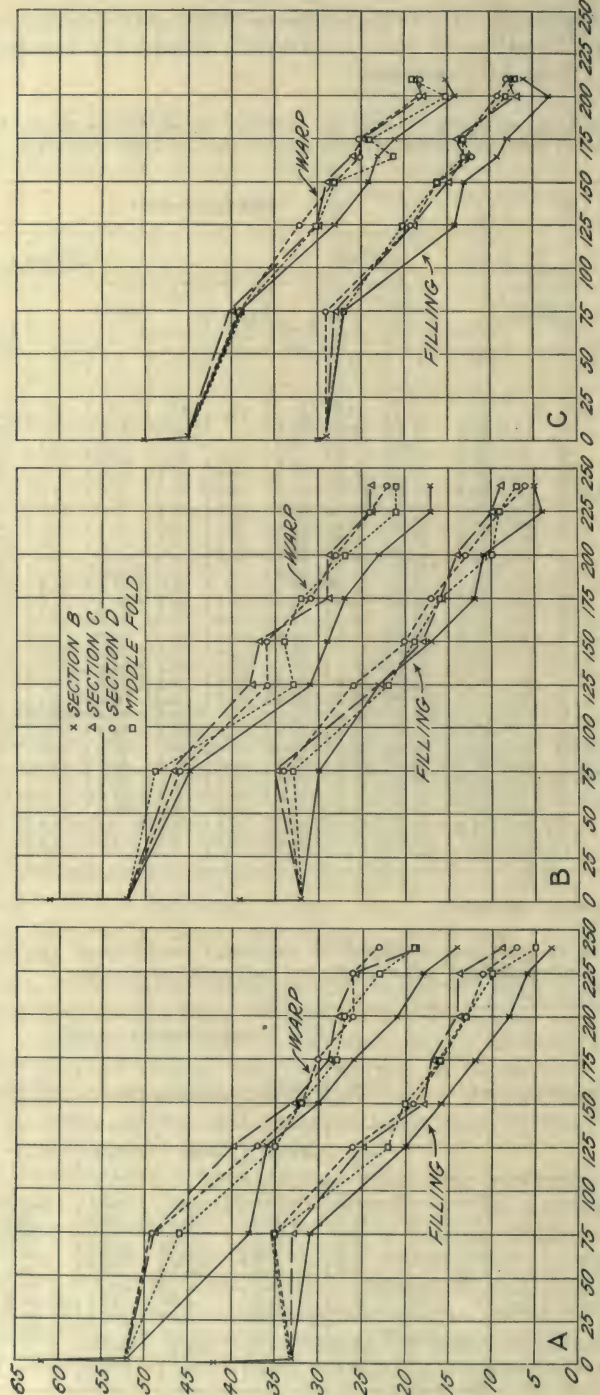


FIGURE 12.—Breaking strengths of three sections and middle fold of sheetings made from the three special cottons. Tests were made of various intervals during wear life: *A*, Good Middling cotton sheeting; *B*, Middling cotton sheeting; *C*, Strict Good Ordinary cotton sheeting.

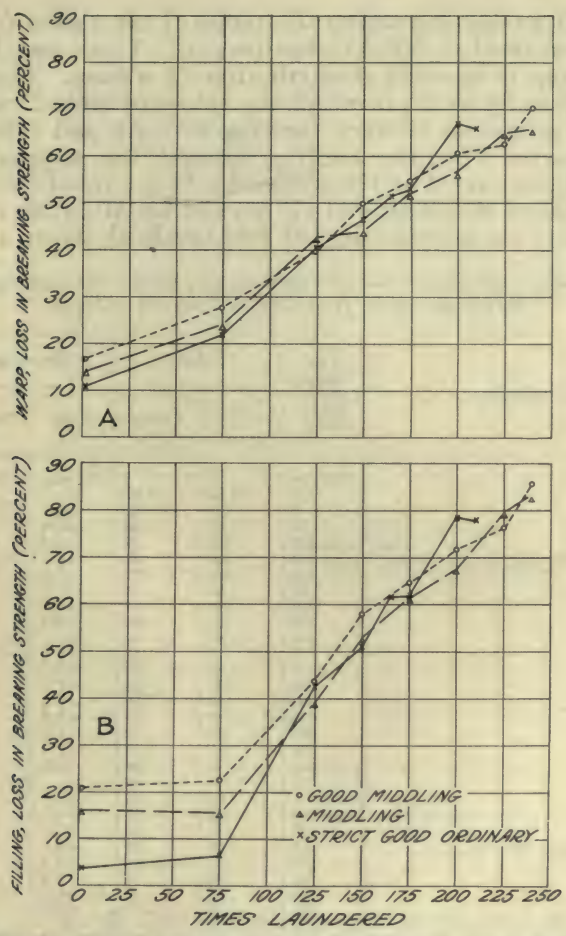


FIGURE 13.—Loss in average breaking strength of laundered sheets made of the three selected cottons: *A*, Warpwise; *B*, fillingwise.

TABLE 21.—*Breaking strength corrected to a 64 by 64 construction for new and laundered sheetings made from the 3 selected cottons*

| Grade of cotton | Direction of test | Gray[1] | Bleached[1] | Corrected testing strength for sheets laundered indicated number of times | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 | 1 | 75 | 125 | 150 | 165 | 175 | 200 | 210 | 225 | 240 |
| | | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* | *Lb.* |
| Good Middling (No. 3) | Warp | 62.0 | 56.7 | 56.0 | 45.8 | 41.5 | 34.6 | 29.5 | ----- | 26.1 | 22.7 | ----- | 21.8 | 17.1 |
| | Filling | 50.3 | 42.7 | 43.0 | 33.6 | 31.8 | 23.3 | 16.9 | ----- | 14.0 | 11.3 | ----- | 9.4 | 5.9 |
| Middling (No. 5) | Warp | 59.7 | 58.0 | 54.0 | 46.3 | 42.4 | 32.1 | 31.6 | ----- | 27.2 | 24.6 | ----- | 20.0 | 19.2 |
| | Filling | 49.8 | 39.4 | 39.8 | 32.9 | 31.2 | 22.7 | 17.8 | ----- | 14.3 | 11.8 | ----- | 7.6 | 6.0 |
| Strict Good Ordinary (No. 8) | Warp | 51.3 | 46.4 | 45.5 | 40.0 | 36.8 | 28.3 | 25.7 | 22.7 | 22.4 | 15.8 | 16.2 | ----- | ----- |
| | Filling | 43.1 | 33.2 | 31.6 | 29.4 | 27.6 | 16.8 | 14.7 | 11.4 | 11.1 | 6.3 | 6.9 | ----- | ----- |

[1] Taken from p. 21.

Bursting strength proved to be a somewhat inaccurate test, as there was considerable variation in the individual values, particularly on sized fabrics. The values in the respective grades after 1

and after 75 washes are within the range of the values for the controls as determined at different test periods. There was, however, a continual drop in bursting strength after 75 washes. This is shown more clearly in figure 16, in which the values of table 23 are plotted. There is a correlation between bursting strength and fabric failure. Breaks appeared when the bursting strength was approximately 28 pounds. This occurred at 125 washes for Strict Good Ordinary, 165 washes for Good Middling, and 175 washes for Middling cotton, and corresponds to the average time of first break, as shown in table 24.

TABLE 22.—*Index, shrinkage, and strength-weight factor for new and launderea sheetings made from the 3 selected cottons*

| Grade of cotton | Test period (times laundered) | Index [1] | | Shrinkage | | Strength-weight factor [2] |
|---|---|---|---|---|---|---|
| | | Warp | Filling | Warp | Filling | |
| | *Number* | | | *Percent* | *Percent* | |
| Good Middling (No. 3) | [3] 0 | [3] 0.87 | [3] 0.67 | | | [3] 25.7 |
| | 1 | .72 | .53 | −3.1 | −1.1 | 20.8 |
| | 75 | .65 | .50 | −6.4 | +4.4 | 19.4 |
| | 125 | .54 | .36 | −7.4 | +3.7 | 16.2 |
| | 150 | .46 | .26 | −6.7 | +6.0 | 12.9 |
| | 175 | .41 | .22 | −7.2 | +4.2 | 11.4 |
| | 200 | .36 | .18 | −7.5 | +4.1 | 9.8 |
| | 225 | .34 | .15 | −7.6 | +4.7 | 9.6 |
| | 240 | .27 | .09 | −5.3 | +0.7 | 7.5 |
| Middling (No. 5) | [3] 0 | [3] .84 | [3] .62 | | | [3] 24.8 |
| | 1 | .72 | .51 | −3.0 | +0.2 | 21.2 |
| | 75 | .66 | .49 | −6.5 | +4.0 | 19.7 |
| | 125 | .50 | .35 | −7.1 | +4.4 | 15.6 |
| | 150 | .50 | .28 | −7.3 | +5.3 | 14.3 |
| | 175 | .43 | .22 | −7.0 | +5.3 | 12.3 |
| | 200 | .39 | .18 | −7.8 | +5.2 | 10.5 |
| | 225 | .31 | .12 | −7.6 | +4.0 | 9.0 |
| | 240 | .30 | .09 | −6.9 | +3.6 | 8.0 |
| Strict Good Ordinary (No. 8) | [3] 0 | [3] .71 | [3] .49 | | | [3] 20.3 |
| | 1 | .63 | .46 | −2.8 | −0.3 | 18.9 |
| | 75 | .58 | .43 | −6.5 | +4.5 | 18.2 |
| | 125 | .44 | .26 | −6.7 | +4.7 | 13.7 |
| | 150 | .40 | .23 | −6.8 | +5.4 | 11.9 |
| | 165 | .35 | .18 | −5.2 | +3.0 | 10.7 |
| | 175 | .35 | .17 | −7.2 | +6.7 | 10.5 |
| | 200 | .25 | .10 | −8.0 | +4.9 | 7.2 |
| | 210 | .25 | .11 | −7.9 | +5.3 | 7.8 |

[1] Index = $\frac{\text{average breaking strength in pounds}}{\text{average thread count.}}$

[2] Strength-weight factor = $\frac{\text{W breaking strength in pounds} + \text{F breaking strength in pounds}}{\text{Weight per square yard in ounces.}}$

[3] Average of controls for 8 test periods.

TABLE 23.—*Bursting strength of sheetings made from the 3 selected cottons, tested after repeated launderings and wear*

| Test period (times laundered) | Bursting strength | | | Test period (times laundered) | Bursting strength | | |
|---|---|---|---|---|---|---|---|
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) | | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| | *Pounds* | *Pounds* | *Pounds* | | *Pounds* | *Pounds* | *Pounds* |
| 0 [1] | [1] 54.6 | [1] 55.0 | [1] 38.2 | 175 | 25.3 | 27.9 | 20.4 |
| 1 | 55.1 | 56.3 | 40.6 | 200 | 22.8 | 23.7 | 14.6 |
| 75 | 53.6 | 56.3 | 44.7 | 210 | | | 13.6 |
| 125 | 36.1 | 41.9 | 28.9 | 225 | 22.6 | 20.9 | |
| 150 | 31.8 | 35.4 | 25.7 | 240 | 11.6 | 16.9 | |
| 165 | | | 17.8 | | | | |

[1] Average of controls for 8 test periods.

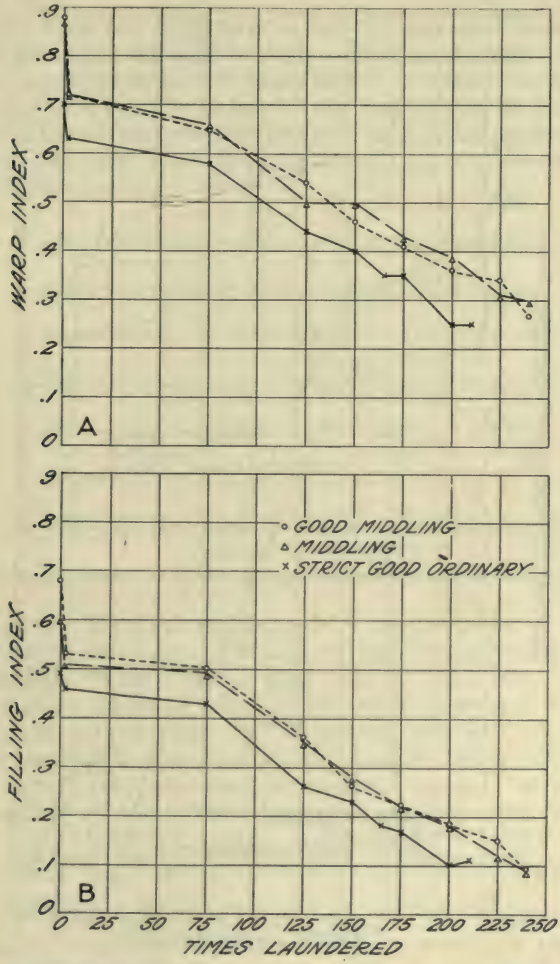


FIGURE 14.—Index $\left[\frac{\text{average breaking strength}}{\text{average thread count}}\right]$ for sheetings made of the three selected cottons and given various amounts of wear: *A*, Warpwise; *B*, fillingwise.

TABLE 24.—*Range, average, and standard deviation of time of first break, and time of removing from service for sheets made of the 3 selected cottons*

| Grade of cotton | First break occurred | | | Removed from service | |
|---|---|---|---|---|---|
| | Range (times laundered) | Average [1] (times laundered) | Standard deviation $\sigma$ | Range (times laundered) | Average [2] (times laundered) |
| | *Number* | *Number* | | *Number* | *Number* |
| Good Middling (No. 3) | 123–198 | 166 | 18 | 222–251 | 237 |
| Middling (No. 5) | 137–205 | 180 | 15 | 223–252 | 239 |
| Strict Good Ordinary (No. 8) | 102–177 | 145 | 20 | 197–217 | 208 |

[1] Average of 26 sheets.

[2] Average of 24 sheets.

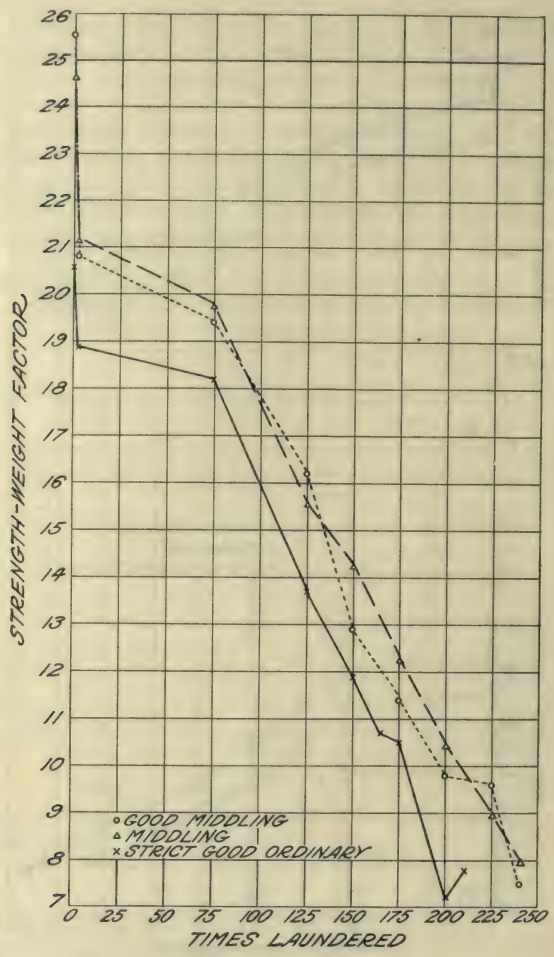
STRENGTH-WEIGHT FACTOR
TIMES LAUNDERED
GOOD MIDDLING
MIDDLING
STRICT GOOD ORDINARY
0 25 50 75 100 125 150 175 200 225 250
7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26

FIGURE 15.—Strength-weight factor $\left[\frac{\text{warp breaking strength} + \text{filling breaking strength}}{\text{weight per square yard}}\right]$ for sheetings made of the three selected cottons, removed from service at intervals of their wear life.

The shrinkage for sheets removed from service is shown in table 25, and indicates that after 75 washes the change in dimensions was very slight. Apparently the gain in width was caused by always ironing from selvage to selvage. This agrees with the observations of McClew (*35*). The change in area is slightly greater than that reported by the Cotton Textile Institute (*5*). The variation in shrinkage for the three different fabrics is not significant.

TABLE 25.—*Average shrinkage of sheetings*[1] *made from the 3 selected cottons*

| Grade of cotton | Length | Width | Area |
|---|---|---|---|
| | *Percent* | *Percent* | *Percent* |
| Good Middling (No. 3) | −7.7 | +3.0 | −4.9 |
| Middling (No. 5) | −7.9 | +3.7 | −4.4 |
| Strict Good Ordinary (No. 8) | −7.6 | +4.1 | −3.7 |

[1] Average of 30 sheets.

None of the controls of all grades which were stored showed a loss in breaking strength during storage. Any variations noted in the breaking strength were of the same order as those due to sampling. The difference between the values at the beginning of the study and the average value of the controls in each case is insignificant. Bursting strength does not show any variation that can be attributed to the effects of storing.

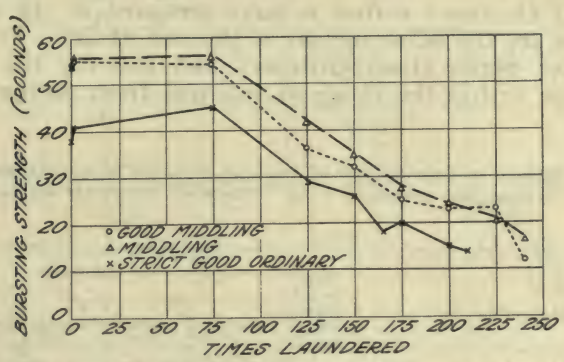


FIGURE 16.—Bursting strength of laundered sheetings made from the three selected cottons.

The life of the sheets as measured by the number of times laundered is given in table 24. The six of each grade used for testing are not included. When, in the judgment of the workers, the sheets were too weak to darn or patch, they were removed from service. Since this personal element was involved, the distribution of the time of first break was also studied and is reported in table 24. This first break may have been due to accident as well as actual wear. However, a study of the life of the sheets and the time of first break shows that the Middling cotton wore slightly better than Good Middling and both of these outlasted the Strict Good Ordinary cotton.

A summary of the record charts showing the location and types of breaks indicates that the maximum wear occurred in the B section and at the selvages for all three grades. The majority of breaks were due to the failure of the filling yarns. Since the sheets were put through the mangle crosswise, creases resulted parallel to the selvages. This weakened the material so that in most cases the selvages were removed eventually and the sheets hemmed. In some instances breaks even occurred along these hems.

The values for the fluidity test, which is a measure of deterioration in cotton, are given in table 26 for the three sheetings. The results show that initially the Good Middling and Middling cottons are of the same order but that the Strict Good Ordinary is weaker. In the case of all three of the selected cottons there is a significant increase in fluidity with service. The appreciable rise in this quantity after the first wash may be attributed to partial removal of starch and other sizing materials. The values for the Strict Good Ordinary cotton indicate that the variation between sheets may be greater than the amount of tendering resulting from 10 washes.

Flow-pressure relationships for the cuprammonium solutions of the three sheetings are illustrated in figure 17 where average rates of flow for the four sections are plotted. The slopes of the lines increase

with fluidity, since rate of flow is used as the ordinate. The lines of least slope in each set of diagrams represent the material after one wash; the lines of steeper slope, the material at intervals during the period of service. The steepest line for the Good Middling and Middling groups gives the flow-pressure relationship for the materials laundered 225 times, and that for the Strict Good Ordinary, after 200 washes. The latter is steeper than the two former, showing that the Strict Good Ordinary cotton is more tendered at the end of 200 washes than are the other cottons at the end of 225. Two hundred washings for Strict Good Ordinary and 225 for the other two sheetings are within the range of removal from service, as shown by table 24.

TABLE 26.—*Fluidity measurements of various sections of sheets made from the 3 selected cottons and removed from service at intervals during their wear life*

| Grade of cotton | Test period (times laundered) | Fluidity | | | | |
|---|---|---|---|---|---|---|
| | | Section A | Section B | Section C | Section D | Average |
| | *Number* | *Reciprocal poises* | *Reciprocal poises* | *Reciprocal poises* | *Reciprocal poises* | *Reciprocal poises* |
| Good Middling (No. 3) | [1] 0 | | | | | [1] 12.1 |
| | 1 | | | | | 13.1 |
| | 75 | 14.5 | 14.9 | 14.2 | 14.2 | 14.5 |
| | 125 | 15.3 | 15.5 | 15.3 | 15.2 | 15.3 |
| | 150 | 17.3 | 17.5 | 17.4 | 17.1 | 17.3 |
| | 175 | 18.2 | 18.5 | 17.7 | 17.9 | 18.1 |
| | 200 | 18.8 | 19.0 | 18.4 | 18.2 | 18.6 |
| | [2] 225 | 18.7 | 19.1 | 18.4 | 18.2 | 18.6 |
| | 240 | 20.2 | 20.7 | 20.2 | 19.5 | 20.2 |
| Middling (No. 5) | [1] 0 | | | | | [1] 12.2 |
| | 1 | | | | | 12.6 |
| | 75 | 15.0 | 15.5 | 14.9 | 14.9 | 15.1 |
| | 125 | 15.8 | 15.9 | 15.4 | 15.3 | 15.6 |
| | 150 | 17.2 | 17.6 | 17.1 | 17.1 | 17.3 |
| | 175 | 17.6 | 18.2 | 18.0 | 17.4 | 17.8 |
| | 200 | 18.4 | 18.8 | 18.4 | 18.3 | 18.5 |
| | 225 | 19.6 | 19.9 | 19.5 | 19.2 | 19.6 |
| | 240 | 20.3 | 20.9 | 20.1 | 19.9 | 20.3 |
| Strict Good Ordinary (No. 8) | [1] 0 | | | | | [1] 13.3 |
| | 1 | | | | | 14.4 |
| | 75 | 15.3 | 15.4 | 15.2 | 15.3 | 15.3 |
| | 125 | 16.4 | 16.5 | 16.3 | 16.1 | 16.3 |
| | 150 | 17.2 | 17.5 | 17.4 | 17.2 | 17.3 |
| | 165 | 17.9 | 18.7 | 18.2 | 18.0 | 18.2 |
| | 175 | 18.4 | 18.7 | 18.3 | 17.9 | 18.3 |
| | 200 | 20.5 | 21.4 | 20.5 | 20.2 | 20.7 |
| | [2] 210 | 19.8 | 20.4 | 19.7 | 19.6 | 19.9 |

[1] Average of 2 sheets.
[2] The results of all the chemical and physical tests made on the sheet removed for testing at this period showed that the sample did not conform to the general trend for the grade.

The yield value, as given by the intercept on the pressure axis is an index to the abnormality of a solution. This value becomes smaller as the fabric of each grade becomes more tendered. Thus, with increasingly severe deterioration of the cotton, the cuprammonium solutions approach the normal behavior of viscous liquids. The yield value also decreases according to the grade of cotton in the order Good Middling, Middling, and Strict Good Ordinary. During approximately the last third of the wear life the yield value is zero.

The fluidity relationship by grade is also illustrated graphically in figure 18, where the average of the four sections is plotted against the number of times laundered. This figure shows that throughout

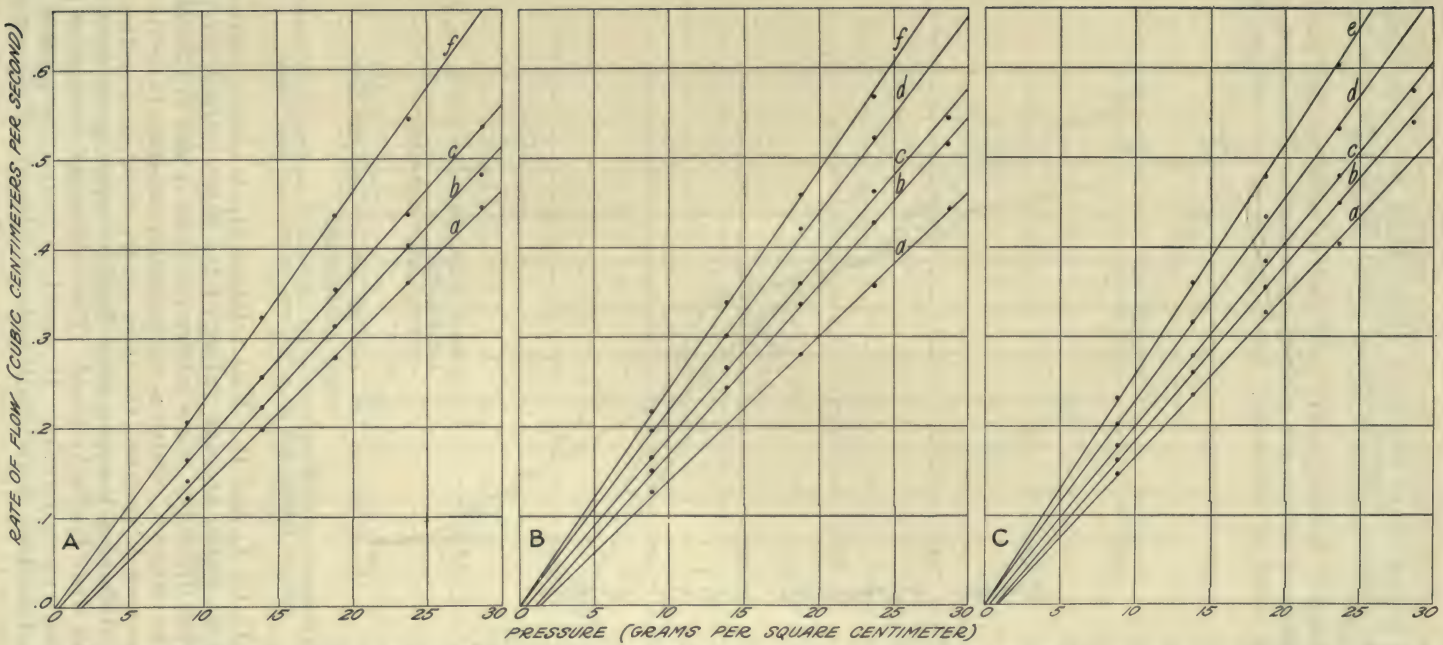


FIGURE 17.—Flow-pressure relationships for cuprammonium solutions of cotton sheetings removed from service at intervals during their wear life: *A*, Good Middling cotton; *B*, Middling cotton; *C*, Strict Good Ordinary cotton; *a*, once; *b*, 75 times; *c*, 125 times; *d*, 175 times; *e*, 200 times; *f*, 225 times laundered.

the period of observation the fluidity values are higher for sheetings made of Strict Good Ordinary cotton than for those made of the other two cottons. Middling and Good Middling cotton are of the same order.

The fluidity measurements recorded in table 26 for each of the three grades of cotton are plotted by sections of the sheet in figure 19. The order of increasing deterioration of the sections for each

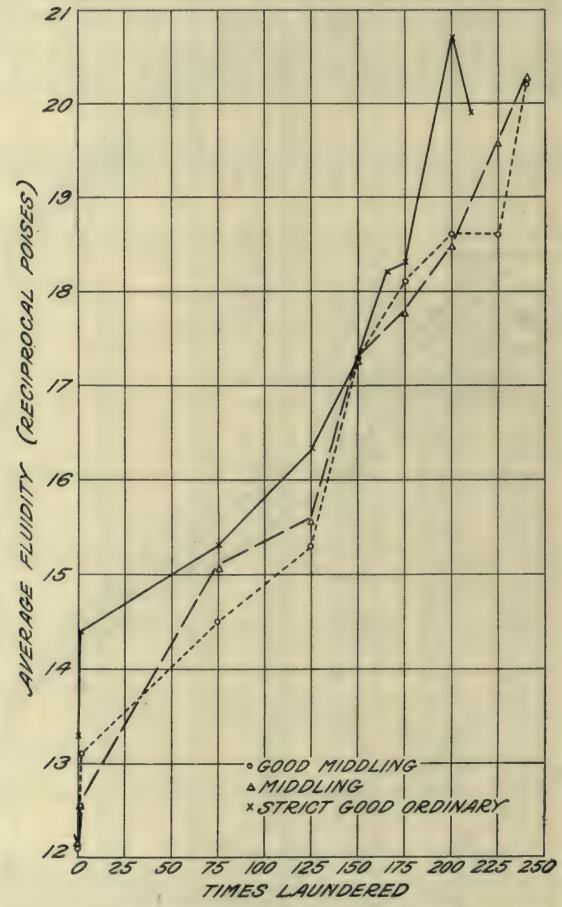


FIGURE 18.—Fluidity values of cuprammonium solutions of sheetings made from the three selected cottons and given different numbers of launderings.

grade is D, C, A, and B. This relationship is shown more clearly in figure 20, where average values of the three cottons are plotted. The greatest difference exists between sections A and B. Section D is superior to section C, which is only slightly superior to section A.

Since section B received the most severe wear, and section D the least, the difference between their fluidity values gives some indication of the wear factor by itself. This difference averages 9 percent of the total rise in fluidity. It would, of course, be greater if section D had not been worn at all, and much greater if the ratio of the

number of launderings to the number of nights used were changed from 1:1 to 1:7 to conform to usual home practice. This is contrary to the opinion expressed in the report of Millard's work (*1*) that the wear factor is negligible in sheets used in hospitals.

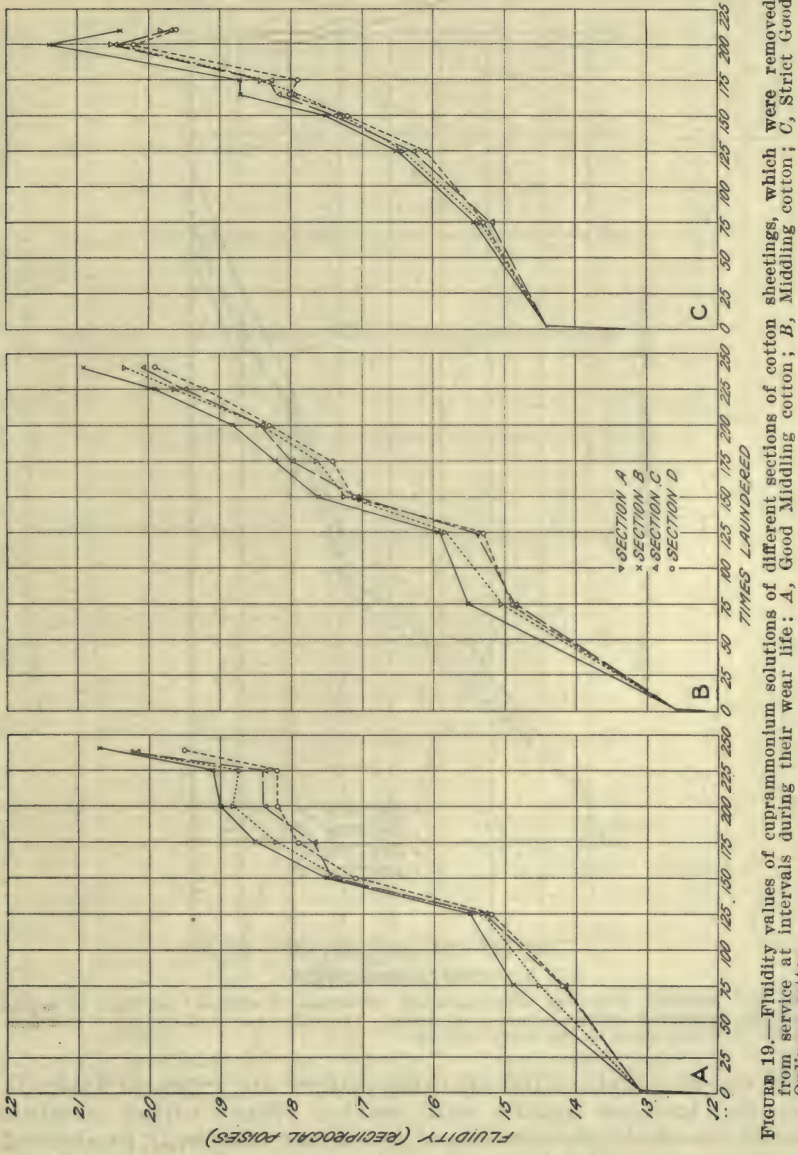


FIGURE 19.—Fluidity values of cuprammonium solutions of different sections of cotton sheetings, which were removed from service at intervals during their wear life: *A*, Good Middling cotton; *B*, Middling cotton; *C*, Strict Good Ordinary cotton.

Deterioration as measured by fluidity appears to be more rapid in the last half of the wear life than in the first half. This is illustrated clearly in figure 20.

In figure 21 the fluidity values are plotted against loss in warp-breaking strength. The graph shows the existence of a linear rela-

tionship between these two quantities. This is also the finding when fluidity measurements are plotted against loss in breaking strength of the filling. Clibbens and Ridge (*16*), who progressively modified cotton yarns by the action of oxidizing agents and acids. found a similar correlation between fluidity and tensile strength.

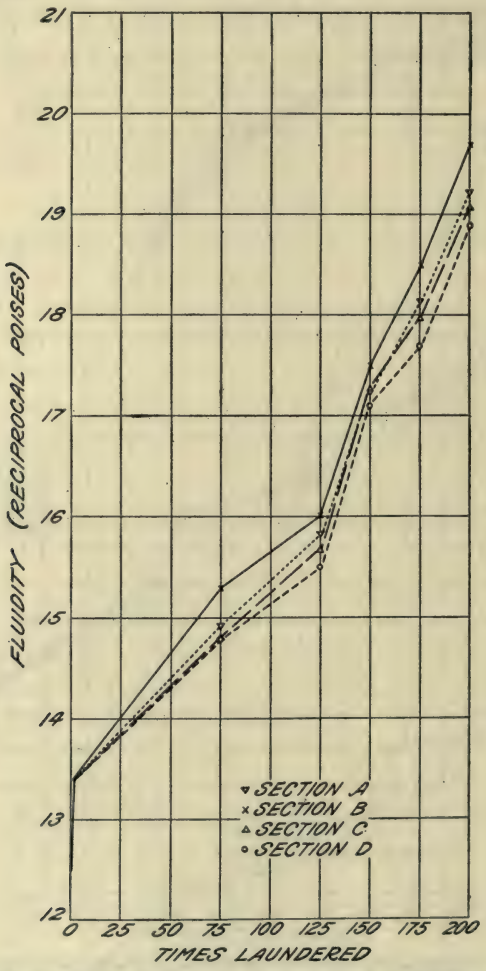


FIGURE 20.—Fluidity values of cuprammonium solutions of different sections of cotton sheetings laundered various numbers of times. The value for each section is the average for sheetings made of the three cottons.

The copper numbers for all three cottons are given in table 27. They also increase steadily with service. Since copper numbers measure chemical deterioration, it is evident that wear produces a progressive chemical deterioration. Again it is apparent that Strict Good Ordinary cotton showed slightly more degradation before it was laundered and at the end of 200 washings than did the other cottons at the end of 225 washings. However, during the major

part of its wear life the Good Middling contained more oxidized cellulose than either of the other cottons.

In figure 22 the values for copper numbers given in table 27 are plotted by sheet sections. The degree of chemical degradation of

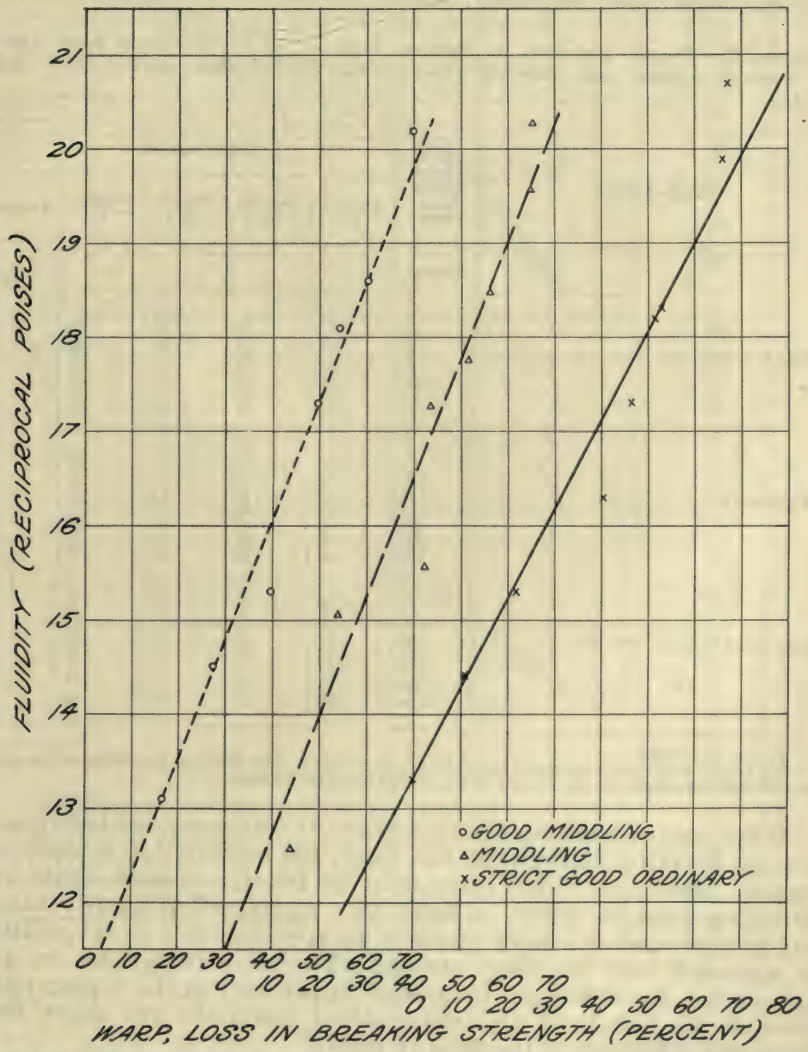


FIGURE 21.—Relationship between the fluidity in cuprammonium solution and the loss in warp breaking strength as compared with a new sheet of each grade. The sheetings were made from the three selected cottons and given various amounts of wear.

all of the fabrics increases in the order, sections D, C, A, and B. This relationship, which is the same as that obtained with the fluidity measurements, is more apparent when the average values of the three grades are plotted, as in figure 23. The increased deterioration of B over that of the other three sections is more evident from copper

numbers than from fluidity results. The average difference in copper numbers between B and D amounts to 9½ percent of the total rise in this value, showing again that wear alone is significant. For both fluidity and copper number this percentage difference decreases in the order Good Middling, Middling, and Strict Good Ordinary.

TABLE 27.—*Copper numbers of various sections of sheets made from the 3 selected cottons and removed from service at intervals during their wear life*

| Grade of cotton | Test period (times laundered) | Copper number of— | | | | |
|---|---|---|---|---|---|---|
| | | Section A | Section B | Section C | Section D | Average |
| | *Number* | | | | | |
| Good Middling (No. 3) | [1] 0 | | | | | [1] 0.29 |
| | 1 | | | | | .38 |
| | 75 | 0.54 | 0.62 | 0.51 | 0.51 | .55 |
| | 125 | .72 | .78 | .70 | .66 | .72 |
| | 150 | .79 | .81 | .81 | .81 | .81 |
| | 175 | .89 | .93 | .87 | .87 | .89 |
| | 200 | .90 | .93 | .91 | .89 | .91 |
| | [2] 225 | .82 | .85 | .78 | .78 | .81 |
| | 240 | .94 | .95 | .91 | .90 | .93 |
| Middling (No. 5) | [1] 0 | | | | | [1] .29 |
| | 1 | | | | | .36 |
| | 75 | .53 | .53 | .51 | .52 | .52 |
| | 125 | .62 | .67 | .57 | .57 | .61 |
| | 150 | .73 | .76 | .71 | .68 | .72 |
| | 175 | .77 | .80 | .79 | .75 | .78 |
| | 200 | .85 | .92 | .85 | .80 | .86 |
| | 225 | .86 | .94 | .90 | .85 | .89 |
| | 240 | .90 | .96 | .90 | .89 | .91 |
| Strict Good Ordinary (No. 8) | [1] 0 | | | | | [1] .32 |
| | 1 | | | | | .39 |
| | 75 | .48 | .53 | .49 | .48 | .50 |
| | 125 | .60 | .63 | .60 | .58 | .60 |
| | 150 | .69 | .75 | .67 | .66 | .69 |
| | 165 | .77 | .80 | .76 | .79 | .78 |
| | 175 | .77 | .81 | .75 | .75 | .77 |
| | 200 | .94 | .94 | .93 | .92 | .93 |
| | [2] 210 | .86 | .91 | .88 | .86 | .88 |

[1] Average of 2 sheets.
[2] The results of all the chemical and physical tests made on the sheet removed for testing at this period showed that the sample did not conform to the general trend for the grade.

When copper numbers for each grade of cotton are plotted against loss in breaking strength of the warp, the relationship is approximately linear, as in the correlation of fluidity measurements and breaking strengths given in figure 21. Again, when fluidity values are plotted against copper numbers an approach to a linear relation is apparent over the range studied. For all three grades, at any test period, the difference (expressed in percent) in the copper numbers of the laundered and unlaundered materials was about four times the difference in the fluidity results.

The methylene blue absorption values (table 28 and fig. 24) show that absorption increases progressively with wear. Increased absorption indicates chemical deterioration. The absorption is greater for the Strict Good Ordinary cotton after 200 washes than for the other grades after 225 washes. However, for the major part of the wear life, the order of increasing absorption is Strict Good Ordinary, Middling, and Good Middling. These findings are similar to those obtained with the copper number test.

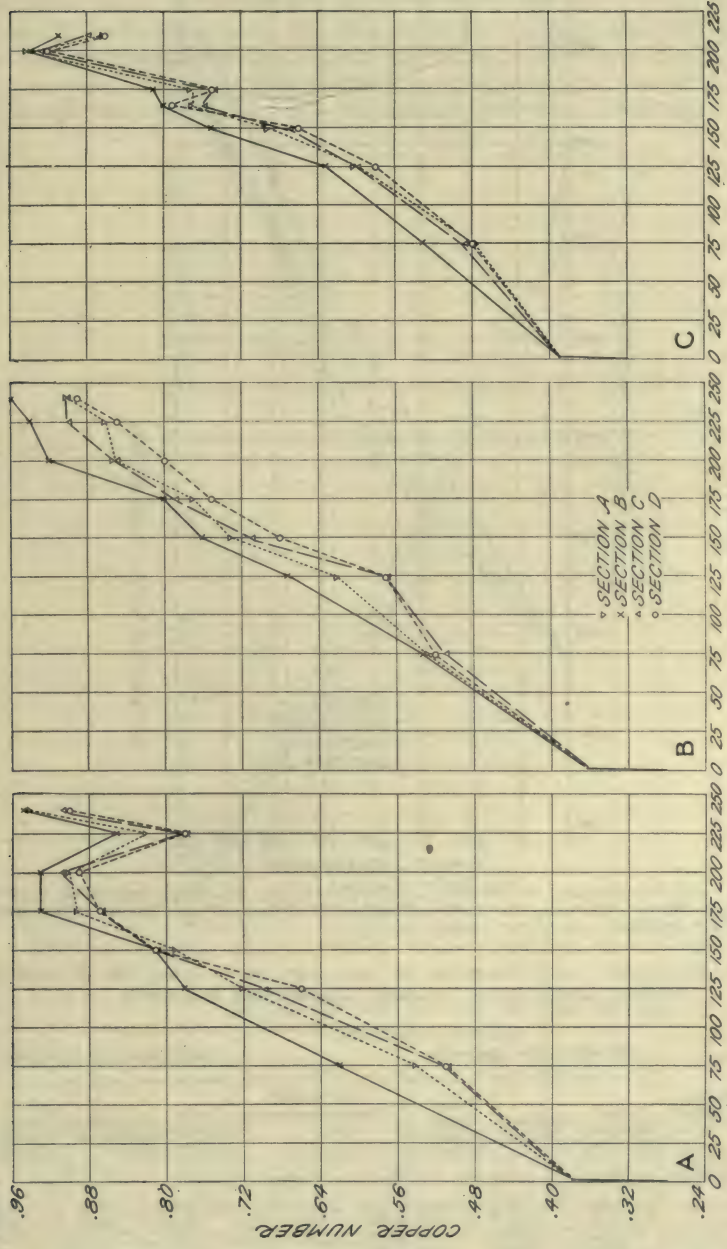


FIGURE 22.—Copper numbers of different sections of cotton sheetings, which were removed from service at intervals during their wear life: *A*, Good Middling cotton; *B*, Middling cotton; *C*, Strict Good Ordinary cotton.

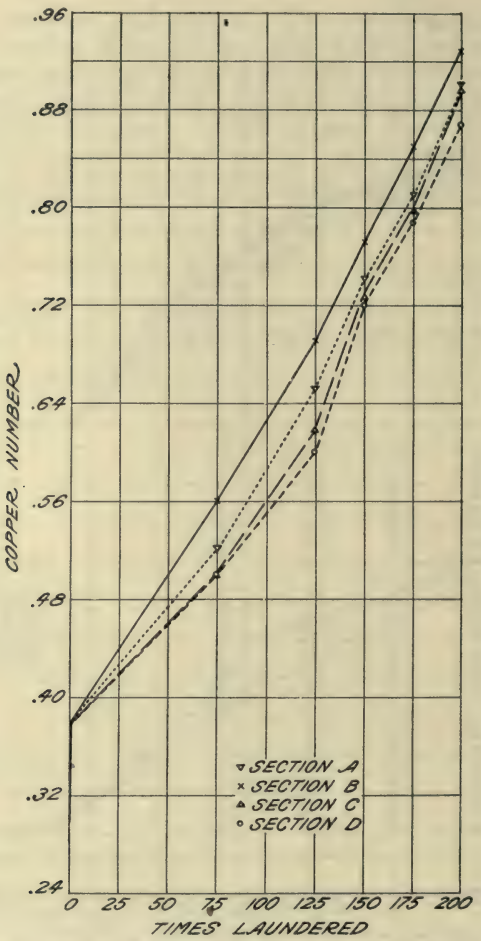


FIGURE 23.—Copper numbers of different sections of cotton sheetings laundered various numbers of times. The value for each section is the average of that for sheetings made of the three cottons.

TABLE 28. *Methylene blue absorption of sheetings made from the 3 selected cottons, tested after repeated launderings and wear*

| Test period (times laundered) | Methylene blue absorption | | | Test period (times laundered) | Methylene blue absorption | | |
|---|---|---|---|---|---|---|---|
| | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) | | Good Middling (No. 3) | Middling (No. 5) | Strict Good Ordinary (No. 8) |
| 0 [1] | [1] 1.88 | [1] 1.87 | [1] 1.82 | 175 | 14.87 | 14.69 | 13.02 |
| 1 | 2.48 | 2.45 | 2.12 | 200 | 15.97 | 15.88 | 17.69 |
| 75 | 7.54 | 7.09 | 6.85 | 210 | | | [2] 17.60 |
| 125 | 10.42 | 10.05 | 9.17 | 225 | [2] 15.72 | 17.05 | |
| 150 | 12.80 | 12.78 | 12.18 | 240 | 17.66 | 17.54 | |
| 165 | | | 13.14 | | | | |

[1] Average of 2 sheets.
[2] The results of all the chemical and physical tests made on the sheet removed for testing at this period showed that the sample did not conform to the general trend for the grade.

Increases in methylene blue absorption were obtained in this study as a result of wear, while in the ironing project the absorption was found to decrease as the temperature rose. At the higher temperatures, however, the rate of this decrease became smaller and the absorption tended toward a limiting value. Barr and Hadfield (*7*), who exposed cotton fabrics to the action of sunlight, found that with exposure the methylene blue absorption decreased somewhat at first

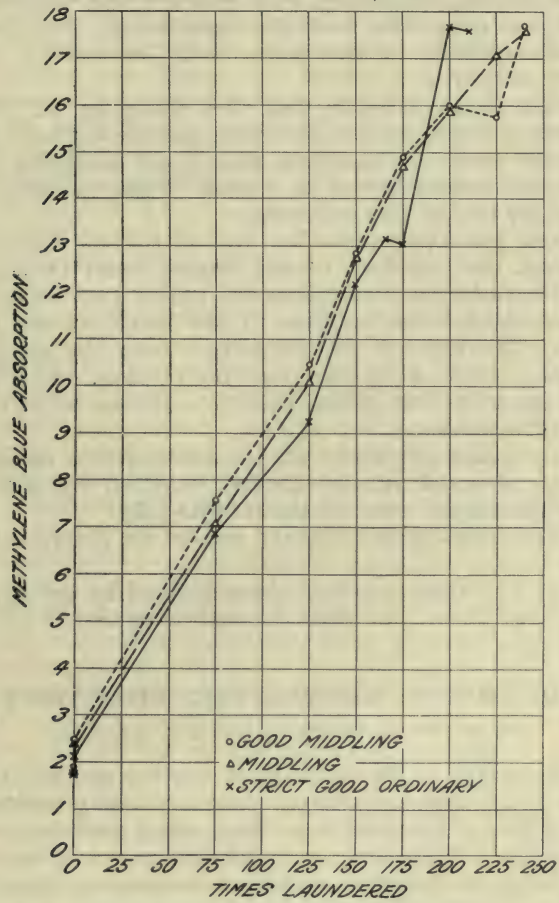


FIGURE 24.—Methylene blue absorptions of sheets made from the three selected cottons and given different numbers of launderings.

and then began to rise. Thus it is obvious that methylene blue absorption is not always a reliable quantitative test for the early stages of oxidation. Taken together with copper number, however, it affords diagnosis of the type of degradation that has occured.

Birtwell, Clibbens, and Ridge (*9*) differentiate between two types of " oxycellulose ", one characterized by a large increase in methylene blue absorption and a relatively small increase in copper number with progressive modification, and the other, the reducing type, by the reverse properties. They obtained the first type by treating

cotton with alkali hypobromite. The present study shows that wear and laundering also produce this type of oxidation product since rapid increases in methylene blue absorption and small increases in copper numbers were observed.

### CONCLUSIONS

Sheets composed of American upland cotton selected to represent the Good Middling, Middling, and Strict Good Ordinary grades were subjected to controlled wear and laundering. The chemical and physical characteristics of the sheets were determined at intervals during their wear life.

The physical tests indicate that the sheetings of Strict Good Ordinary cotton were weaker initially and throughout their wear life than those made of Middling and Good Middling cotton and were slightly more deteriorated at the end of 200 washings than were the others at the end of 225 washings.

As measured by copper number and methylene blue absorption determinations, the cellulose of the Strict Good Ordinary cotton showed less degradation throughout the major part of the wear life of the sheets than did the cellulose of the Middling and Good Middling cotton. However, at 200 washings, when the sheets of Strict Good Ordinary cotton were worn out the cellulose was slightly more deteriorated than was that of the other two cottons at the end of their service after 225 washings.

Both chemical and physical tests showed that the maximum wear on the sheets occurred in the section occupied by the shoulders. There was no increased wear on the middle fold.

Three and one half years' storage caused no deterioration in unused sheets.

The type of oxidation product characterized by greatly increased affinity for methylene blue was formed as a result of wear and laundering.

## EFFECTS OF IRONING TEMPERATURES UPON THE FABRICS[16]

By K. Melvina Downey and Ruth E. Elmquist

As part of a study of the reaction of various grades and varieties of cotton to wear and laundering, data are being accumulated by the Bureau of Home Economics on the physical and chemical changes which take place during ironing in fabrics woven of known grades of cotton. Such information assists in evaluating these grades in terms of the usefulness of the finished fabric and also in formulating recommendations for laundering procedures. Methods of analysis sensitive to small amounts of damage have been used, as well as strength tests which measure more obvious deterioration. This is particularly desirable as the repeated use of high temperatures just below those giving changed measurements for breaking strength may result in an unexpectedly shorter wear life for the fabric.

Experiments in which cotton has been subjected to moderate heat over prolonged periods of time have been described by such ob-

[16] Grateful appreciation is expressed to Doris M. Buchanan, who has given valuable assistance during this investigation. Judith L. Steele has also given aid in compiling data and Jeanne D. Guerin in making breaking-strength tests.

servers as Fort (*19*), Schüler (*48*), Knecht (*32*), Justin-Mueller (*30*), Bain (*6*), Möllering (*37*), Tiltman and Porritt (*50*), Akahira (*2*), Patel (*46*), and Ramsbottom (*47*). The results of these and similar studies are not applicable to ordinary ironing procedures where higher temperatures are applied to only one side of a fabric for a very short time. Even in the reports of ironing studies from which some recommendations have been made to the laundry trade, there has been no indication of work on known grades of cotton under controlled conditions of pressure and moisture. In all cases scorch was detected merely by color change visible to the eye under ordinary lighting conditions, and breaking strength appears to be the only measure recorded of deterioration in the ironed cotton.

Some work with hand irons has been described by Fort (*19*), Knecht and Muller (*33*), and Gilmore (*23*). Since the term scorch has been defined so qualitatively in the published reports of these observers, it is difficult to compare their results. Fort, as well as Knecht and Muller, made comparative temperature observations by means of a thermometer inserted in the iron from the top. Their reports are vague as to the ironing conditions when the danger point for cotton was reached. Gilmore, who worked with an electrically heated hand iron, states that there was visible yellowing on bleached cotton materials without accompanying loss in breaking strength. However, Clayton (*13*, *29*) who subjected such fabrics to a heating plate at various temperatures reports that he obtained a loss in tensile strength at temperatures far below those causing visible scorch. This apparent contradiction may be attributed to differences in moisture content according to the experimental results of Knecht and Muller (*33*), or it may be due to difference in the time of contact with the heated surface. In Gilmore's work the time of contact was 5 seconds and in Clayton's 30 seconds.

In the present investigation the fabrics used were made under experimentally controlled conditions from selected cottons representative of known grades. They were ironed under controlled conditions of moisture, pressure, and temperature with a household ironer (fig. 25), in which a padded roll turns against a heated metallic shoe.[17] With the partial spectrophotometric method used for detecting color change in the ironed materials, it was possible to note measurable effects for ironing temperatures considerably lower than those at which there was visible yellowing in ordinary daylight. Tests were made on the ironed cotton samples not only for losses in breaking strength but also for changes in the chemical nature of the cloth.

### ANALYSIS OF DESIZED SHEETINGS

The preparation and construction of the materials used in this study are described on page 3 and the results of the wearing tests to which the finished sheetings were subjected on page 29. They were woven of Good Middling, Middling, and Strict Good Ordinary cotton respectively. The finishing process included a soda kier-boil and chemicking with a one fourth of 1 percent available chlorine solution.

[17] This ironer was supplied through the courtesy of the Apex Electrical Manufacturing Co.

Ironing studies were made on the new sheetings and also on used ones removed from service at various intervals during their wear life. Before being submitted to the heat tests, the new sheets which had been treated in the finishing plant with a mixture of corn starch and a saponified tallow softening material, were desized as follows: The fabric was given a preliminary soaking and rinsing in water at 90° to 100° F. It was then washed in a solution of neutral soap in the temperature range 140° to 150° and rinsed in hot distilled water until the pH of the rinse water was the same as that of the distilled water used. This was followed by two separate enzymic treatments under controlled temperature conditions with thorough rinsing after

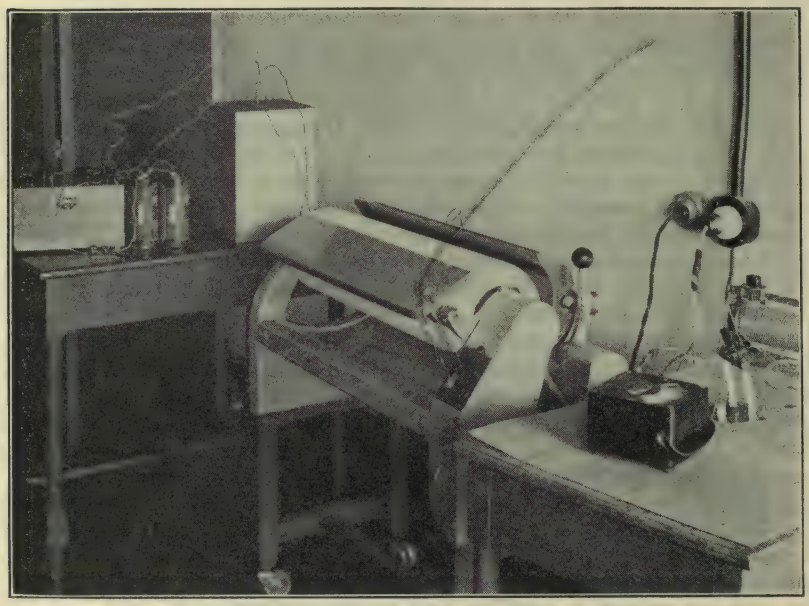

FIGURE 25.—Experimental ironing equipment.

each treatment. The material was finally washed again and rinsed until the pH of the wash liquor was the same as that of the distilled water.

Loss in weight due to this desizing was determined by weighing fringed and thoroughly conditioned samples under standard atmospheric conditions (65 percent relative humidity and 70° F.). This loss ranged from 4.2 to 4.8 percent for all three sheetings. The fat and wax content of the desized fabrics, as determined by extraction with carbon tetrachloride according to the general procedure of Clifford, Higginbotham, and Fargher (*17*), varied from 0.35 to 0.42 percent. Tests for chlorides and sulphates gave negative results. These tests were made because such salts would produce abnormal tendering of the cotton under the influence of heat.

The weight per square yard, thickness (as measured with a micrometer thickness gage exerting a constant pressure), and thread count of the new desized sheetings are given in table 29.

TABLE 29.—*Weight, thickness, and thread count of desized sheetings made from the 3 selected cottons*

| Grade of cotton | Weight | Thickness | Thread count | |
|---|---|---|---|---|
| | | | Warp | Filling |
| | *Ounces per square yard* | *Inches* | | |
| Good Middling (No. 3) | 4.1–4.2 | 0.0113–0.0123 | 73 | 66 |
| Middling (No. 5) | 4.0–4.2 | .0110– .0120 | 73 | 65 |
| Strict Good Ordinary (No. 8) | 3.8–4.0 | .0105– .0118 | 72 | 64 |

### IRONING EQUIPMENT AND PROCEDURE

An especially constructed household ironer having a roll 26 inches long and 7 inches in diameter was used for applying heat to the fabrics. In order to hold the high temperatures desired, an 1,800-watt heating element was provided in the shoe. This element, of the flat ribbon type, was well embedded in a composition insulating material and when placed in position next to the metallic mass of the shoe was further insulated from the rear frame by layers of asbestos. A sheet of copper about 23 inches long was placed between the insulated heating element and the metal mass of the shoe to serve as an equalizer of temperature over the most used area of the shoe. By means of a variable resistance placed in the heating circuit, it was possible to compensate for changes in the line voltage as well as for cooling effects produced by the fabrics while being ironed.

The temperature of the heated shoe was determined from potentiometric readings of the electromotive force generated when the thermocouple junction with its leads was placed in the metal just below the ironing surface. Preliminary measurements had been made to determine the necessary depth of immersion of the thermoelement in the iron mass of the shoe.[18]

All thermocouples used in this work were made from no. 30 B. & S. gage chromel and constantan wires which had been enameled and then wound with asbestos. On account of the necessary forward and backward motion of the shoe in starting or stopping, it seemed advisable to use rather sturdy materials. As has been confirmed recently by Kratz and Broderick (*34*), the chromel-constantan combination also gave the advantage of a comparatively high electromotive force per degree of temperature change. Each thermocouple was calibrated by the United States Bureau of Standards, but no appreciable difference was found.

Preliminary thermocouple measurements taken for a distance of 15 inches along the central portion of the 26-inch shoe gave practically no variation over that distance. Accordingly, for the ironing of samples 15 inches wide, it was only necessary to make temperature observations in the middle portion of the surface in contact with the sample. There was then no danger of short circuits from thermocouples placed at various positions in the metal. The total ironing surface of the shoe amounted to approximately 140 square inches.

[18] Acknowledgment is made to W. P. White, of the Geophysical Laboratory, Carnegie Institution of Washington, for criticisms and suggestions in this connection.

The revolving roll of the ironer was well padded with two layers of ⅝-inch knit cotton padding and two layers of napped, double-faced cotton felt. Over this, covers of preshrunk muslin were used. These were changed often to avoid possible contamination of the experimental samples from any oxidized cellulose which might be formed on the covers with repeated use. The padding was fluffed up and aired often so as to prevent uneven packing on the roll.

Measurements upon the compressed springs at the back of the shoe indicated an average pressure between the padded roll and the heated shoe of 1¼ to 1½ pounds per square inch. This same pressure setting was maintained throughout the study.

Preparatory to ironing, sheeting samples 19 by 15 inches were conditioned at 65 percent relative humidity and 70° F. for 6 hours, a length of time sufficient according to the results described by Sommer (*49*). In order to estimate the moisture content, weighings were made of representative conditioned samples before and after drying to constant weight at 105° C. The values thus obtained for moisture content are: Good Middling, 6.22 to 6.25 percent; Middling, 6.18 to 6.32 percent; Strict Good Ordinary, 6.34 to 6.45 percent.

In order to keep the moisture content constant before ironing, each conditioned sample was wound on a moisture-proof roll between two similar pieces of conditioned cloth. The roll was then wrapped in moisture-proof material and placed in a covered container which had been standing open in the conditioning room. Weighings of samples which had been wrapped as described showed the moisture content to be practically unchanged even after the rolls had been removed from the conditioning room for 1 week. This finding confirms the experience of Guest and Potsdamer (*27*) in their work on fabric conditioning.

Each sample was run through the ironer once. The entire time required for any part of a given sample to pass the heated metallic shoe was about 2½ seconds.

The surface of the roll just before making contact with the heated metal was 38° to 40° C. for the major portion of the work. However, some observations were also recorded when the surface of the roll had a temperature range of 120° to 130°. In the course of household ironing, the roll surface sometimes rises to these temperatures, due to the turning of the roll against the heated shoe when no articles are being passed through the ironer. In order to estimate the approximate temperature of the roll surface, the thermo element, covered with a heat-retaining pad, was placed in position on a thin copper sheet which could be easily bent to make close contact with the roll. Checks made with this arrangement under known conditions showed it to be sufficiently accurate for this purpose.

#### MEASUREMENTS OF DETERIORATION

Measurements were made upon the ironed samples to detect changes in breaking strength, in surface color, and in the chemical nature of the cloth. The same tests were made on undamaged control samples of the same warp and the same filling taken from the immediate vicinity of the samples on which measurements were made. For the results recorded in this report, the values obtained from

the control samples from any one grade of sheeting were averaged, and the test results expressed with reference to the average control value for the type of sheeting involved. The lowest ironing temperature tabulated is 145° C. since preliminary tests showed that the samples ironed at that temperature gave the same results as unironed samples.

### BREAKING STRENGTH

Strips 6 inches long and 1 inch wide were used for the tensile-strength measurements, which were obtained under standard conditions of humidity and temperature with a Scott tester having a 3-inch back and front jaw and a distance between the top and bottom jaws of 3 inches. The rate of separation of the jaws was 12 inches per minute.

### SURFACE REFLECTANCE

Tests for changes in color were made by means of a partial spectrophotometric method described by Appel (*4*). The intensity of light reflected by the samples was measured with reference to a standard magnesium oxide surface for the following range of wave lengths: 703, 651, 578, 546.1, 501, 435.8, and 405 millimicrons. The measurements of the light reflection in the violet range (mercury lines 435.8 and 405 millimicrons) were the most effective in detecting slight surface changes due to ironing, and it was possible to distinguish the damaged from the undamaged samples by observations for wave length 435.8 millimicrons.

The general arrangement of the apparatus and the position of the sample in its rotary holder is shown in figure 26.[19] The test sample and the standard white surface are mounted in interchangeable positions on the sliding platform. For an observation this is moved back so that the sample and standard are directly under the source of light. The 220-volt mercury arc lamp, as well as the 1,000-watt tungsten filament lamp, are mounted in the sliding carriage, which may be shifted to the right or left, according to the illumination desired for the sample. Readings are obtained with the Martens photometer, which is fixed in position so that the line of vision is perpendicular to the reflecting surface underneath. A more detailed description of this apparatus has been published by Appel (*4*).

### FLUIDITY IN CUPRAMMONIUM SOLUTION

Fluidity (viscosity) tests were found to be a satisfactory means of measuring a tendered condition in ironed samples. These tests depend upon the fact that a cuprammonium hydroxide solution of the damaged cotton flows through a capillary tube more rapidly than does a similar solution of the undamaged cloth. The general method of observation followed that of Herschel and Bulkley (*28*), in which the time of flow for successive 5-cc portions is obtained. Figure 27 illustrates the particular arrangement of the fluidity tubes used in this laboratory. The constant temperature bath used accommodates 4 tubes, allowing 3 to come to the required temperature (25° C.) while measurements are being made on the fourth. The average

[19] Acknowledgment is made to the Textile Section of the Division of Fibrous and Organic Materials, U.S. Bureau of Standards, for the use of this equipment.

diameter of each capillary tube was obtained from flow tests with oils, the viscosities of which had been determined by the United States Bureau of Standards.

While the cuprammonium solution used for these fluidity measurements was of the same general type employed by Clibbens and

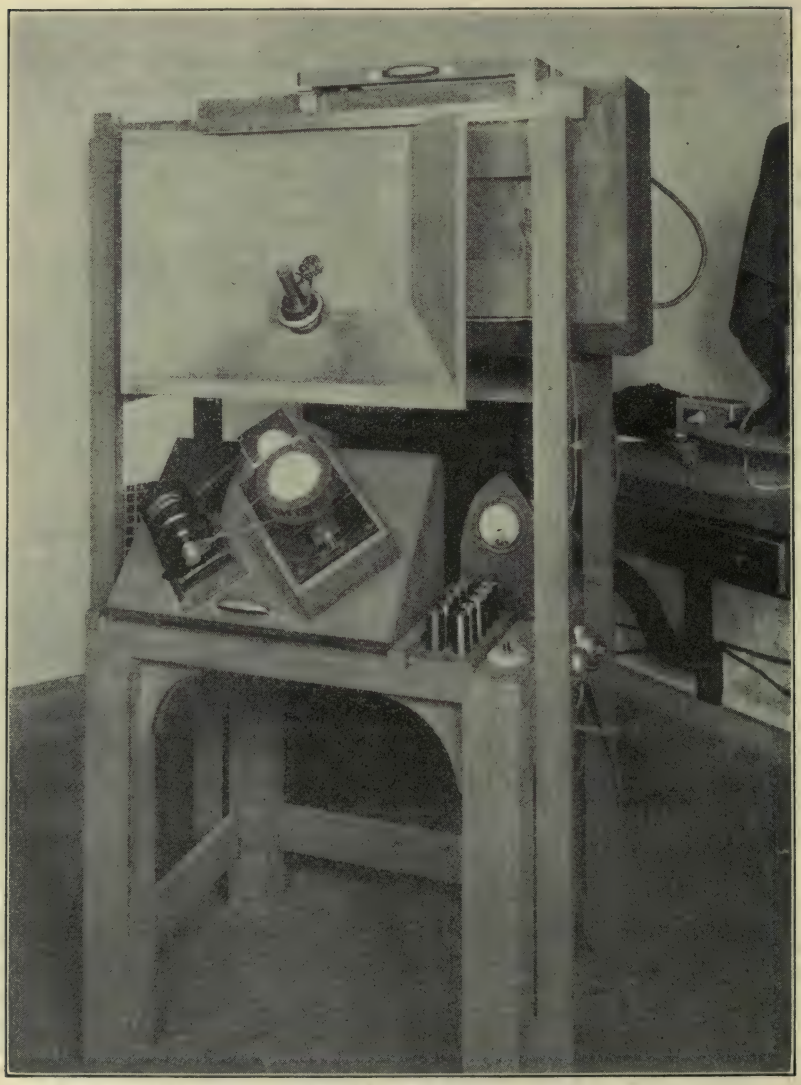

FIGURE 26.—Apparatus for the measurement of light reflectance.

Geake (*15*) modifications were made in its analysis (*11*, *12*). A solution containing 15 grams of copper, 200 grams of ammonia, and less than 0.5 gram of nitrite per liter was carefully prepared. As it was necessary during preparation to protect the solution from both heat and light, ice and a covering impervious to light were placed around the tube containing the electrolytically prepared copper and

the concentrated ammonium hydroxide to which 10 grams of sucrose per liter had been added. Purified air was bubbled through this mixture until the desired concentration of copper was reached. After the final solution had been analyzed and diluted to the proper concentration of copper and ammonia, it was stored in an atmosphere of

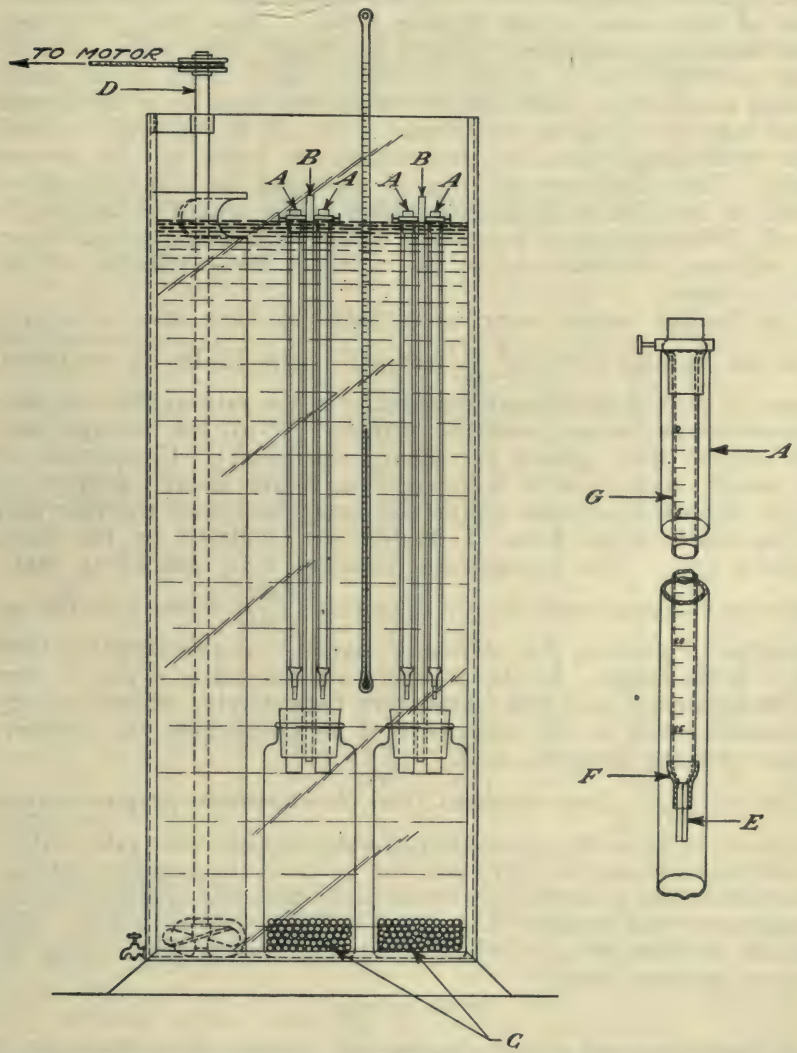


FIGURE 27.—Viscometer arrangement: *A*, Viscometer in glass jacket; *B*, air outlet tube; *C*, shot used for weight; *D*, axis leading to stirrer; *E*, capillary tube in position for observation; *F*, rubber connection; *G*, viscometer tube graduated in cubic centimeters.

nitrogen in a cool, dark place. As this solution decomposes under certain conditions within approximately 1 month, new solutions were made up from time to time.

The fabric test samples for the fluidity measurements were finely divided in a nonheating mill, which had a cutting action and was equipped with 1-millimeter openings through which the disinte-

grated fabric passed. Solution was also facilitated by the use of steel cylinder stirrers. Breakage of viscometers was avoided when the stirrers were fitted with spiral steel springs at each end as recommended by Neale and Stringfellow (*39*). After the finely divided cotton was thoroughly conditioned under standard procedure, sufficient amounts were weighed out to make 0.5-percent solutions of this cotton in the fluidity tubes. These tubes were then filled with cuprammonium, slipped into black cloth jackets and rotated overnight on a special viscosity wheel. This wheel, made of solid composition board, has four times the capacity of the bicycle wheel used by Clibbens and Geake (*15*). It is equipped on both sides with metal fasteners into which the tubes can be pressed easily. This eliminates the loss of time and the difficulty which would be involved in binding the tubes to the spokes of the bicycle wheel. When the cotton was finally dissolved in the cuprammonium, the solution was ready to be run through the capillaries of the fluidity tubes.

The fluidity results recorded in table 30 have been calculated from the formula $F=\frac{q}{C(P-p)}$, where $F$ is the fluidity in reciprocal poises, $C$ is an instrumental constant, $q$ is the rate of flow in cubic centimeters per second, and the quantity, $(P\text{-}p)$, the average pressure causing flow (grams per square centimeter). Comparison of the cotton solutions with a true viscous liquid showed them to be for all practical purposes within the range for which the flow may be expressed in the form of fluidity as calculated by the above formula (*15*). The instrumental constant $C$ is defined in centimeter-gram-second units by the quantity $\frac{\pi g d^4}{128L}$, where $g$ is the acceleration of gravity, $d$ is the inner diameter of the capillary tube, and $L$ is the length. In the present work the values $d$ and $L$ were 0.1136 centimeters and 3.23 centimeters, respectively. Kinetic energy corrections were for the most part of no significance for measurements upon the materials used.

The ratio $\frac{q}{P-p}$ was obtained from flow-pressure graphs such as are shown in figure 28, where the ordinates represent the rate of flow, $q$, and the abscissae the corresponding value of the pressure head, $P$. The yield value, $p$, is given by the distance from the origin to the intersection of the straight line graph with the pressure axis. The method of Herschel and Bulkley (*28*) was used in determining the average pressure heads.

### COPPER NUMBER

Determinations of copper number and of methylene blue absorption gave additional information both as to the extent and type of the degradation products formed in the ironing of the cotton materials. A method of determining the copper number of cotton and its use as a measure of the deterioration of this fiber has been discussed by Elmquist (*18*). In this study, a sample of the fabric weighing 1.5 grams was prepared in the same way outlined in that paper. However, in order to insure results that would be readily reproducible from day to day, the finely divided samples were treated with

Braidy's solution instead of Fehling's solution (*10*). Each of these samples, which had been placed in Erlenmeyer flasks fitted with Bunsen valve stoppers, was heated for 3 hours in an oil bath thermostatically controlled at 100° C. The copper number, as reported, is the number of grams of copper reduced from an alkaline solution of cupric sulphate by 100 grams of dry cotton.

TABLE 30.—*Physical and chemical changes caused by various ironing temperatures on desized sheetings made from the 3 selected cottons*

[Temperature of ironer roll, 38° to 40° C.]

| Grade of cotton | Temperature of ironing surface | Fluidity | Copper number | Methylene blue absorption | Reflectance relative to magnesium oxide (wave length, 435.8) | Tensile strength [1] | |
|---|---|---|---|---|---|---|---|
| | | | | | | Warp | Filling |
| | *°C.* | *Reciprocal poises* | | | | *Pounds* | *Pounds* |
| Good Middling (No. 3) | 145 | 13.38 | 0.426 | 1.77 | 0.842 | 61.0 | 42.0 |
| | 243 | 13.38 | .426 | 1.77 | .842 | 61.0 | 42.0 |
| | 246 | 13.38 | .426 | 1.77 | .832 | 61.0 | 42.0 |
| | 254 | 13.38 | .426 | 1.77 | .825 | 61.0 | 42.0 |
| | 257 | 13.41 | .429 | 1.73 | .820 | 61.0 | 42.0 |
| | 271 | 13.80 | .469 | ---- | .804 | 61.0 | 42.0 |
| | 287 | 13.96 | .480 | 1.57 | .790 | 61.0 | 42.0 |
| | 303 | ---- | ---- | ---- | .776 | 61.0 | 42.0 |
| | 320 | 14.55 | .491 | 1.51 | .752 | 58.3 | 40.3 |
| | 335 | 15.11 | .540 | 1.49 | .725 | 53.3 | 37.4 |
| Middling (No. 5) | 145 | 13.96 | .444 | 1.78 | .828 | 57.8 | 37.3 |
| | 243 | 13.96 | .444 | 1.78 | .828 | 57.8 | 37.3 |
| | 245 | 13.96 | .444 | 1.78 | .813 | 57.8 | 37.3 |
| | 257 | 14.04 | .451 | 1.73 | .805 | 57.8 | 37.3 |
| | 271 | 14.29 | ---- | 1.67 | ---- | 57.8 | 37.3 |
| | 287 | 14.57 | .516 | 1.62 | .772 | 57.8 | 37.3 |
| | 303 | ---- | ---- | ---- | .762 | 57.8 | 37.3 |
| | 320 | 15.24 | .552 | ---- | .739 | 54.6 | 35.6 |
| | 336 | 15.78 | .580 | 1.52 | .708 | 49.4 | 32.8 |
| Strict Good Ordinary (No. 8) | 145 | 14.89 | .473 | 1.77 | .812 | 50.0 | 32.2 |
| | 243 | 14.89 | .473 | 1.77 | .812 | 50.0 | 32.2 |
| | 246 | 14.89 | .473 | 1.77 | .803 | 50.0 | 32.2 |
| | 255 | 14.89 | .473 | 1.77 | ---- | 50.0 | 32.2 |
| | 257 | 14.91 | .476 | 1.73 | 797 | 50.0 | 32.2 |
| | 271 | 15.24 | .500 | 1.68 | .782 | 50.0 | 32.2 |
| | 304 | 15.63 | .523 | 1.60 | .759 | 50.0 | 32.2 |
| | 320 | 16.14 | .564 | ---- | .731 | 47.7 | 30.8 |
| | 334 | 16.36 | .581 | 1.55 | .707 | 44.8 | 29.4 |

[1] Strip method.

ABSORPTION OF METHYLENE BLUE

The methylene blue absorption was determined in a neutral solution of methylene blue buffered with potassium dihydrogen phosphate and sodium hydroxide. The ironed samples were cut as for the copper number and the fluidity measurements; otherwise the method followed was that of Clibbens and Geake (*14*). When the finely divided cotton had been thoroughly conditioned, 2.5-gram samples were added to 15-cc portions of the methylene blue solution in special tubes. Care was taken to insure thorough wetting. After standing 18 hours, the solution was separated by centrifuging and 10 cc of this titrated against napthol yellow S, one molecule of which couples with two molecules of methylene blue. The absorption of methylene blue in millimols per 100 grams of dry cotton is calculated from the difference of titer of 10 cc before and after immersion of the cotton.

### DISCUSSION OF RESULTS

In the interpretation of results obtained in this study, no change was regarded as significant which was less than 1 percent of the value given by the undamaged material. All changes in the ironed fabrics were corroborated by repeated tests, and the representative results summarized. A general examination of the values shows that a deteriorated condition exists in the test samples at ironing temper-

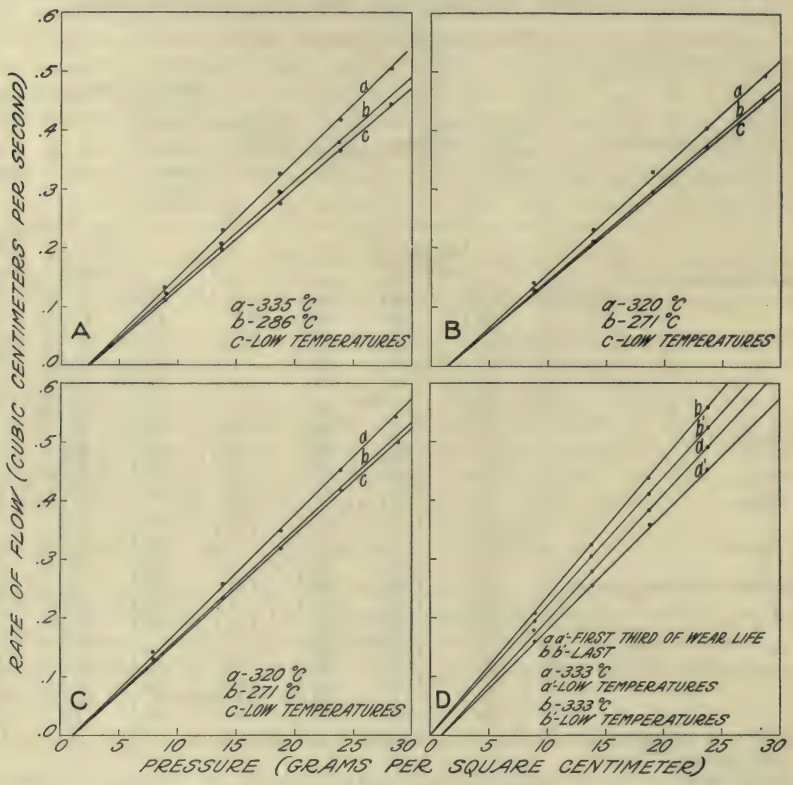


FIGURE 28.—Flow-pressure relationships for cuprammonium solutions of desized cotton sheetings ironed at various temperatures: *A*, Good Middling cotton; *B*, Middling cotton; *C*, Strict Good Ordinary cotton; *D*, used sheetings (Strict Good Ordinary cotton).

atures considerably lower than those at which a loss in breaking strength is first evident. There are no striking differences in the resistance to heat shown by the three sheetings under the experimental conditions of the present study. While there is some indication that high ironing temperatures have less effect on sheeting made from Strict Good Ordinary cotton, any conclusion in regard to this must be made with some reservation, particularly since this material after desizing was somewhat lower in weight and thickness than the other two sheetings.

### NEW DESIZED SHEETINGS

Representative test results for the three desized sheetings ironed on the cooler roll surface are given in table 30. For the desized materials, before being ironed, there is an increase in breaking strength

and surface reflectance as well as a decrease in copper number and fluidity in the following order: Strict Good Ordinary, Middling, Good Middling. The fluidity values and the copper numbers both give slight indication of deterioration in the desized materials ironed at 257° C., while at 271° changes of several percent are noticeable in the fluidity values and even larger relative changes in the copper numbers. After the first slight indications of damage the copper number appears to increase more rapidly than the fluidity for samples ironed at the same temperatures. The sensitiveness of the copper-number determinations to the deteriorated condition in the ironed materials seems to indicate that the modified cellulose here is entirely of the reducing type. This deduction is further strengthened by the values for the methylene blue absorption which decrease as the temperatures rise. At the higher temperatures the rate of this decrease becomes smaller and the absorption tends toward a limiting value. The same reducing type of oxidation product described here was obtained by Barr and Hadfield (*8*) when they exposed cotton fabrics to sunlight in the presence of air or oxygen. Changes of a similar nature due to mild oxidation with chlorine were also described by Birtwell, Clibbens, and Ridge (*9*).

There was no marked variation in the amount of tendering received by the different sheetings as shown by the flow-pressure diagrams of the cuprammonium solutions of cotton (fig. 28, A, B, C). These graphs also show that the yield value as represented by the intercept on the pressure axis apparently decreases with the lower grades of cotton. The line *c* in each individual group was obtained with a solution of the undamaged material. The faster flow of the solution of damaged material is shown graphically by the lines of greater slope. For both the Middling and the Strict Good Ordinary cotton, line *a* gives the flow-pressure relationship obtained with a solution of the material ironed at 320° C. The data in table 30 show that 320° is in the temperature range for which changes in breaking strength were first evident. Line *a* in the sheeting group of Good Middling cotton represents the flow-pressure relation for a solution of material ironed at 335°. At this temperature the loss in the breaking strength of the Good Middling cotton sheeting varied from 11 to 13 percent.

A review of the results shows that the modified cellulose obtained under the conditions of this study was always accompanied by a measurable loss in the surface reflectance of the fabrics for light of wave length 435.8 millimicrons. However, since there are so many factors which may be responsible for surface color change, other tests must be made to determine the nature and extent of degradation. Surface changes, as measured by the reflectance, appeared at ironing temperatures as low as 245° to 247° C.

The curves in figure 29 are representative of the reflectance results obtained when the desized materials are ironed with the cooler roll. Curve *a* in each group represents the results given by the undamaged material. A comparison of the lower curves with this one shows that the greatest relative change in light reflection occurs in the violet part of the spectrum (435.8 and 405 millimicrons).

Curves *d* and *e* in each group are the only ones showing a noticeable change in the red part of the spectrum (651 and 703 millimi-

crons). These are of special interest since they were obtained with samples ironed at temperatures high enough to produce measureable loss in tensile strength (320° and 334° to 336° C.). For the samples ironed at 303° to 304° no change in relative reflectance can be noted at 703 millimicrons, and there is only a very slight difference at 651 millimicrons.

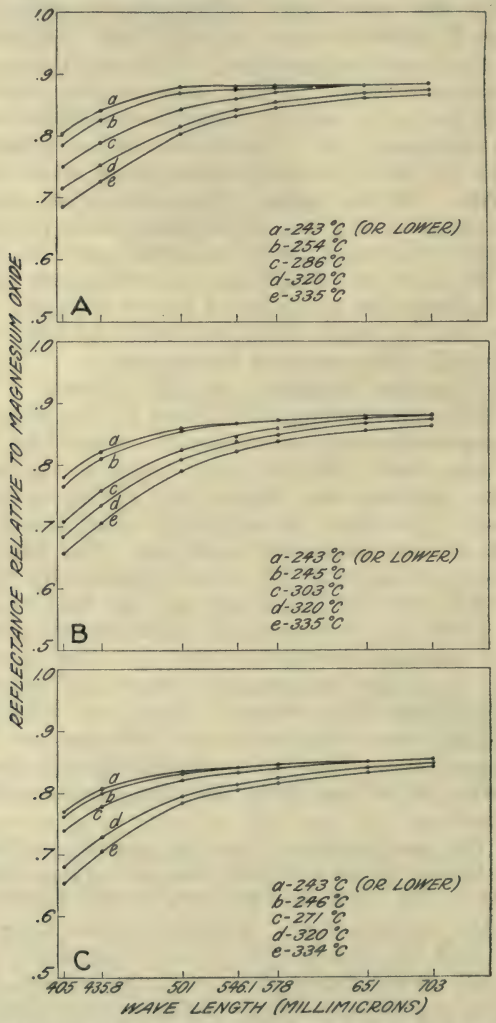


FIGURE 29.—Reflectance curves for new desized sheetings ironed at various temperatures: *A*, Good Middling cotton; *B*, Middling cotton; *C*, Strict Good Ordinary cotton.

The general experimental conditions represented in table 31 differ from those of table 30 only in the higher surface temperature of the roll (120° to 130° C.). As this is only an occasional condition in the average household ironing procedure, it seemed unnecessary to make extensive observations with the hotter roll. The results obtained with the three different sheetings gave no conclusions inconsistent with those already drawn from table 30. They suggest the

same type of altered cellulose characterized by increased fluidity, higher copper numbers, and lower methylene blue absorption. The first indications of change in any of these three quantities occurred in the temperature range 224° to 226°, and in general, the changes noted appeared at temperatures fully 30° below those giving similar results with the cooler roll surface.

TABLE 31.—*Physical and chemical changes caused by various ironing temperatures on desized sheetings made from the 3 selected cottons*

[Temperature of ironer roll, 120° to 130° C.]

| Grade of cotton | Temperature of ironing surface | Fluidity | Copper number | Methylene blue absorption | Reflectance relative to magnesium oxide (wave length, 435.8) |
|---|---|---|---|---|---|
| | °C. | *Reciprocal poises* | | | |
| Good Middling (No. 3) | 145 | 13.38 | 0.426 | 1.77 | 0.842 |
| | 218 | 13.38 | .426 | 1.77 | .842 |
| | 220 | 13.38 | .426 | 1.77 | .829 |
| | 226 | 13.50 | ---- | ---- | .821 |
| | 232 | 13.59 | .453 | ---- | .804 |
| | 244 | ---- | ---- | 1.66 | .796 |
| | 259 | 14.31 | .485 | 1.60 | .785 |
| Middling (No. 5) | 145 | 13.96 | .444 | 1.78 | .828 |
| | 218 | 13.96 | .444 | 1.78 | .828 |
| | 219 | 13.96 | .444 | 1.78 | .818 |
| | 224 | 13.96 | .444 | 1.76 | .810 |
| | 232 | 14.47 | .465 | 1.70 | .790 |
| Strict Good Ordinary (No. 8) | 145 | 14.89 | .473 | 1.77 | .812 |
| | 217 | 14.89 | .473 | 1.77 | .812 |
| | 220 | 14.89 | .473 | 1.77 | .803 |
| | 224 | 14.89 | ---- | 1.76 | .797 |
| | 232 | 15.12 | .493 | 1.72 | ---- |
| | 239 | ---- | ---- | 1.69 | ---- |
| | 258 | 15.56 | .511 | ---- | .773 |
| | 285 | 16.04 | ---- | ---- | .747 |

Measurements of the violet light (wave length, 435.8 millimicrons) reflected from the surface of the ironed samples indicated a decreased reflectance at 220° C. With the cooler roll the same relative changes occurred in the range 245° to 247°.

Tests for breaking strength on sheeting of Strict Good Ordinary cotton gave approximately a 9 to 10 percent loss at 292° C. and between 3 and 5 percent at 285° C. These are at least 30° lower than the temperatures giving the same changes with the cooler roll. Similar results were obtained with the other two cottons.

### USED SHEETINGS

The diagrams in figure 28, D, give the flow-pressure relationship for solutions of used cotton sheetings ironed on the cooler roll surface. The two lower lines, $a$, $a'$, were obtained for sheeting ironed at the end of the first third of its wear life at temperatures 333° and 145° C., respectively. The lines, $b$, $b'$, represent flow-pressure relations for sheeting in the last third of its period of use. It is evident that a solution of the more used material shows a smaller relative change in its flow than does the less worn material under the same range of ironing temperatures. While the results illustrated here were obtained with sheetings of Strict Good Ordinary cotton, the

same changes were obtained with the Good Middling and the Middling during the last half of their wear life. A comparison of C and D in figure 28 shows that the new desized sheeting has approximately the same yield value as the used material at the end of the first third of its wear life, but during the last half of the period of use the yield value shifts to zero. This was also the finding with the two sheetings woven from Good Middling and Middling cotton.

The numerical values of the fluidity given by some of the more worn material for the low and high ironing temperatures (145° and 333° C.) were 20.2 and 21.3, respectively. For the same temperature range the copper numbers of this material were 0.892 and 0.996, indicating no unusually large change. Contrary to the usual decrease in methylene blue absorption obtained with the newer materials, there was an increase for the more worn sheetings. However, at the end of the first third of its useful life, this material gave only slight increases in absorption, and in the first one tenth of its wear life there was a decided decrease under the same ironing conditions. If additional results confirm this change to an increase in methylene blue absorption for worn materials generally under the influence of heat, it is possible that absorption measurements on materials heated under controlled conditions could be used in developing a method to distinguish used cotton from new. The need for such a test has been stressed by Winne and Donovan (*56*) in the examination of filling materials used in bedding and upholstered furniture.

The reflectance curves given by the used cotton sheetings ironed with the cold roll at 145° and 333° C. are shown in figure 30. The sheeting at the end of one third of its wear life gives about the same relative decrease in surface reflection at 435.8 millimicrons as is given by new sheeting with approximately the same ironing temperature. However, after two thirds of its useful life this material shows a much greater relative decrease in reflectance. The same relatively large surface change existed at 330° to 334° for all samples measured during the last third of the period of use regardless of the fact that the weights decreased from 3.7 to 3.3 ounces per square yard. This same type of surface change was found with all three sheetings, but the results given here were obtained with the sheeting woven from Strict Good Ordinary cotton.

In view of the increased darkening of the most worn materials at high ironing temperatures, determinations were made of the fat content as well as the pH extract of the unironed materials. Even for the sheeting in the last period of its wear life the fat content was not found to be essentially different from that of the new desized materials. The pH of the extract obtained from 5-gram samples of both the worn and the new materials immersed in 100 cc of boiling water for 1 hour according to a method described by New (*40*) was approximately the same as that of the distilled water used. All the worn sheeting materials used in these experiments were thoroughly rinsed in distilled water before being ironed. It is of course possible that the darkening of the fabrics in their more worn state may be somewhat analogous to the condition described by Fort (*20*) in connection with the heat test applied to tendered cotton. His method, however, was developed as a means of detecting oxida-

tion tendering, which may not be particularly great for materials under normal conditions of use. The yellowing effect upon oxidation products of the reducing type has also been recorded by Birtwell, Clibbens, and Ridge (*9*).

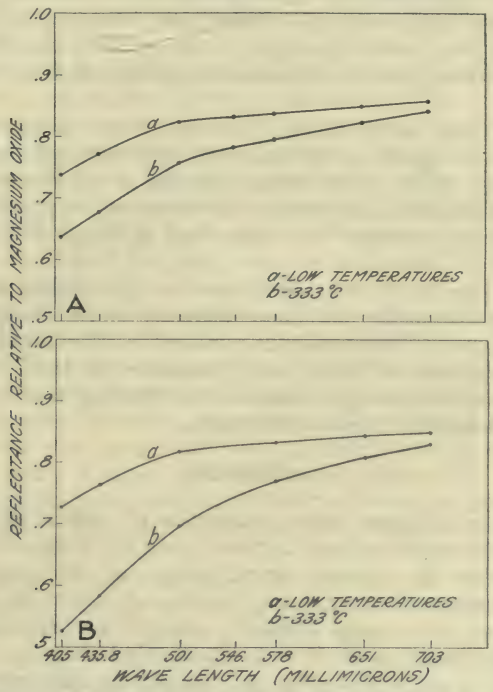


FIGURE 30.—Reflectance curves for used sheetings made of Strict Good Ordinary cotton: *A*, First third of wear life; *B*, last third of wear life.

## CONCLUSIONS

Three sheetings made from selected cottons representative of the Good Middling (No. 3), Middling (No. 5), and Strict Good Ordinary (No. 8) grades, respectively, were ironed at known temperatures with a household ironer of the roll type with a pressure between 1¼ and 1½ pounds to the square inch. Each fabric sample was conditioned at 65 percent relative humidity and brought in sliding contact with the heated metallic shoe for about 2½ seconds.

The desized materials damaged by ironing were characterized by increased fluidity in cuprammonium solution, higher copper numbers, and comparatively low methylene blue absorption as well as by a decreased surface reflectance in the violet part of the spectrum.

Similar changes were obtained in the three types of sheeting under the ironing conditions described. The Strict Good Ordinary showed a slightly greater resistance to heat than the other two, but the sheeting of this cotton was found to be somewhat lower in weight and thickness after desizing than were the others.

At ironing temperatures above 245° C. changes were observed in all the sheetings when the initial surface temperature of the padded roll was 38° to 40°. The first appreciable loss in tensile strength ap-

peared in the range 315° to 320°. Slight indications of chemical deterioration were obtained as low as 256° to 257° and changes in surface reflectance first occurred at 245° to 247°.

When the roll surface attained a temperature from 120° to 130° C., indications of deterioration were obtained for ironing temperatures 25° to 30° lower than with the cooler roll. At 220° a decreased surface reflectance was noted for light in the violet part of the spectrum, and the first indications of chemical degradation occurred from 224° to 226°.

In the first third of its useful life the worn sheeting of all three types scorched no more easily than the new desized material. However, in the last third of its wear life the worn material was much more easily darkened, as shown by a decreased surface reflectance at the higher temperatures. It also had a higher methylene blue absorption.

An ironing procedure was developed in this study which involved the control, maintenance, and measurement of the temperature of the ironer, the control of the moisture content of the fabric to be ironed, and the regulation of time and pressure factors. The methods described are applicable to research on ironing and on temperature effects in finishing during manufacture.

## SUMMARY

In an effort to compare some properties of cotton fibers, yarns, and fabrics, and to furnish a basis for studying the relation of the quality of raw cotton to the service, laundering, and ironing properties of fabrics manufactured from them, 3 bales of American upland cotton from the Texas area, crop 1928–29, selected to represent each Good Middling, Middling, and Strict Good Ordinary grades, approximately 1 inch in staple length, and similar in character, were manufactured into sheeting of a definite construction and subjected to service and ironing tests. The described conditions and procedures employed were controlled and were comparable, insofar as possible.

Observations were made on the behavior of the cottons during manufacture and some precise measurements were obtained on the fibers in the raw stocks and on their intermediate products, yarns, and fabrics; certain physical and chemical analyses were made on the sheets as a basis of determining their serviceability and their resistance to ironing conditions. The setting of the problem, the materials and procedure employed, the results obtained, and the specific conclusions drawn are presented in the distinct but closely related parts of the bulletin.

In considering the findings here reported, it should be pointed out that the observations made are generally in line with those previously made in experimental and commercial manufacture of cottons of different grades. In certain instances, the three cottons have not given results which would be anticipated from their grade designations. However, the grade factors do not refer to fiber properties which in the final analysis must largely control the spinning behavior and the yarn and fabric characteristics. Within any given grade, for instance, these fiber properties may vary greatly and it is this variability which mills seek to overcome by mixing the stock

from a considerable number of bales. Samples in the form of individual bales taken from certain grade categories, therefore, can give only a limited picture of the average and range of spinning quality associated with grade. It is believed, nevertheless, that the present results are well worth while for indicating something of the range of results to be obtained from the different grades and for orienting the attack in future studies.

The Good Middling and Strict Good Ordinary cottons furnished waste in quantity considered average for their respective grades; the Middling cotton gave somewhat less waste than the average of this grade. During the course of manufacture, the length of fibers from the three cottons did not change appreciably. The number of ends broken per 100 spindles per hour increased with decreasing grade. As a result of the finishing process, a reduction of about 14 percent occurred in the width of the sheeting, accompanied by about a 3-percent increase in length.

The brilliance of the raw cottons decreased as the grade became lower and, although the spread became smaller after bleaching, this relation was evident for the cottons throughout their manufacture. In general, the spectrophotometric measurements made on the fabrics established a similar relation, but some differences in reflection were observed between the gray and the bleached fabrics, as explained. Although the gray fabrics manufactured from the lower grades showed on the average a larger number of fine particles of foreign matter, the finished fabrics were practically free of such extraneous matter.

The yarns made from the Good Middling and Middling cottons were approximately equal in strength; those from the Strict Good Ordinary were 10 to 18 percent weaker than those from either of the other two grades. The corrected tensile strength of the gray and of the bleached fabrics decreased as the grade became lower, but the relative strength of the fabric from the Middling cotton was much nearer to that for the Good Middling than to that for the Strict Good Ordinary. The bursting strength of the gray and of the bleached fabrics from the Good Middling and Middling cottons was about equal and was much higher than that of the corresponding fabrics made from the Strict Good Ordinary. Bleaching resulted in a reduction of approximately 33 percent in bursting strength for the fabrics.

The changes in the physical and chemical characteristics of the sheetings that were made from these three selected cottons and subjected to controlled service and laundering were determined at intervals during their wear-life. Tests were made for weight, thread count, thickness, breaking strength, bursting strength, shrinkage, fluidity in cuprammonium solution, copper number, and methylene blue absorption.

As measured by physical tests the sheets of Strict Good Ordinary cotton were weaker initially and throughout their period of wear than those made of Middling and Good Middling cotton. The latter two were of the same order. The sheets woven of Strict Good Ordinary were slightly more deteriorated at the end of 200 washes than were the others at the end of 225. The copper number and methylene blue absorption tests in this study showed that the cellulose

of the Strict Good Ordinary cotton was less degraded during the major part of its wear life than was that of the other two cottons. However, in the last stages of wear it was slightly more deteriorated. The oxidation product formed was characterized by greatly increased affinity for methylene blue.

The maximum wear occurred on all of the sheets at the section usually occupied by the shoulders. There was no increased wear on the middle fold and no change in the unused sheets after 3½ years' storage.

The new sheetings made of the selected cottons were desized and ironed under controlled conditions of temperature, time, pressure, and moisture. The ironing procedure was developed with a household ironer of the roll type in which the pressure maintained between the roll and the heated shoe was 1¼ to 1½ pounds per square inch. The time of sliding contact of the sample with the shoe was about 2½ seconds.

When the initial surface temperature of the padded roll was 38° to 40° C., no changes were produced in the cottons at ironing temperatures below 245°. At the highest ironing temperatures used all desized sheetings showed a lower breaking strength, a decreased surface reflectance in the violet part of the spectrum, increased fluidity in cuprammonium solution, higher copper numbers, and a comparatively low methylene blue absorption.

There was some indication of a slightly greater heat resistance for the desized sheeting made from Strict Good Ordinary cotton than for the other two sheetings. Before being damaged by ironing this desized material made from Strict Good Ordinary cotton had lower values for breaking strength and surface reflectance as well as higher values for copper number and fluidity than the sheetings from Middling and Good Middling cotton.

Worn sheetings made of the three selected cottons were subjected to the same ironing conditions after different periods of service. During the first third of their useful life they all showed physical and chemical changes similar to those obtained with the new desized materials. However, in the last third of their wear life, the worn materials showed a greater decrease in surface reflectance and a higher methylene blue absorption.

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# FIELD AND LABORATORY STUDIES ON THE BEHAVIOR OF THE LARVAE OF THE SWINE KIDNEY WORM, STEPHANURUS DENTATUS[1]

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## ECONOMIC IMPORTANCE OF KIDNEY WORMS

The swine kidney worm, *Stephanurus dentatus*, has long been recognized as a serious menace to the raising of hogs. The magnitude of the losses it occasions has been stressed not only in the United States but also in other countries, particularly Australia. Shealy and Sanders (*10*)[2] consider this nematode one of the most injurious internal parasites of swine in the southern part of the United States and the economic losses attributable to it nearly as large as those caused by ascarids. Nighbert and Connelly (*2*) estimate that losses due, for the most part, to kidney worms, incident to the dressing of carcasses, amount to $80,000 annually in one packing house in Georgia. This estimate, however, does not take into account the stunted growth and unthriftiness shown by Schwartz and Price (*8*) to be a result of infestations with this parasite.

Losses from kidney worms, moreover, are not confined to swine alone, since agamic forms of this parasite are of common occurrence in the livers of cattle in certain parts of the South, according to these authors (*9*). The presence of these immature worms in cattle livers results, as does their presence in swine livers, in considerable losses owing to the condemnation or necessary trimming of affected parts, according to Schwartz (*6, 7*). In discussing the swine kidney worm

[1] This investigation was carried out in the field laboratory of the Zoological Division at Moultrie, Ga.
[2] Italic numbers in parentheses refer to Literature Cited, p. 17.

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he states that this parasite constitutes an actual and potential menace to the swine industry of the southern part of the United States.

Ross and Kauzal (*5*) report that in certain parts of Australia this nematode is not only one of the commonest parasites of swine, but is also one of great importance from an economic standpoint. The incidence of infection with the kidney worm in certain parts of Queensland is reported by these writers to be as high as 70 percent of all pigs killed. They add:

> There is evidence that the number of infections is increasing, as is also the severity of infestations in individual pigs.

## SCOPE OF THE INVESTIGATION AND THE APPARATUS USED

In view of the serious losses caused by kidney worms in regions where these parasites are prevalent, it is important that control measures be instituted. These measures must be based on the life history of the parasite, more particularly on its behavior during the preparasitic stages. The results of a study conducted at Moultrie, Ga., on the bionomics of the preparasitic stages, are presented in this bulletin.

In carrying out this investigation the following program was followed: (1) The distribution of larvae in hog pastures and the conditions under which larvae were present were studied by means of the Baermann apparatus; (2) the longevity of the infective larvae, under conditions similar to those in which they were found in nature, was determined; (3) the effects of various environmental conditions upon the eggs and larvae of this parasite were determined; (4) the reactions of the infective larvae to environmental stimuli were noted; (5) the migrations of the infective larvae on soil and on grass were studied both experimentally and under field conditions; and (6) the effect of growing crops on land infested with kidney worms was determined by means of the Baermann apparatus.

The Baermann apparatus used to isolate kidney-worm larvae from soil consisted of a large glass funnel 8 or 9 inches in diameter, with a short rubber tube attached to its stem, a clamp to close the lower end of this tube, and a copper sieve about 5½ inches in diameter, having a 1-mm mesh, which was placed inside the funnel. In order to prevent, so far as possible, small particles of soil from sifting through into the funnel, the sieve was lined with two thicknesses of unbleached muslin.

In routine procedure a battery of several funnels was used. The soil to be examined was thoroughly broken up, and a layer, 2 or 3 cm deep, was placed in the cloth-lined sieves. The sieves were then placed in the funnels, and water at a temperature of about 95° F. was poured over the rims of the funnels until the level of the water was above that of the soil. After a period of from 4 to 6 hours, approximately 1 liter of water was drawn off from each funnel, into a beaker, and allowed to settle for 1 hour. At the end of that time the supernatant fluid was drawn off and the residue examined for *Stephanurus dentatus* larvae. Corn husks and grass, after being cut up with scissors, were also examined for larvae in this manner.

## DISTRIBUTION OF KIDNEY-WORM LARVAE ON HOG PASTURES

Soil samples were collected at weekly intervals from pastures where the hogs were known to be infested with kidney worms. These samples were then examined, in the manner previously described, for the presence of infective and preinfective larvae. Owing to the immense amount of work involved in searching for kidney-worm larvae among the hundreds of soil nematodes recovered in each Baermann isolation, quantitative determinations of the numbers of larvae in soil taken from these pastures were made in only two instances.

The greatest concentration of kidney-worm larvae was found on moist soil beneath piles of corn husks, corncobs, and other debris occurring on the areas on which the hogs were fed. It was observed that the farmers, in the locality investigated, stored corn unhusked in order to protect it from insects. On most of the farms under observation the practice of feeding this unhusked corn on the ground at the same place each day resulted in an accumulation of corn husks and cobs to a depth of almost a foot in some instances. The soil beneath this debris, being protected from the drying action of the sun and wind, in many cases remained moist even over prolonged dry periods. In observing the activities of hogs on these farms, it was noted that the animals usually gathered at the feeding grounds, at irregular intervals during the day, to root through the piles of debris in search of feed. It was further observed that usually one or more of the animals urinated during this period, and that the urine, containing kidney-worm eggs, was soon covered with debris thrown about by other hogs. Under these conditions, animals frequently swallowed infective larvae which had hatched from eggs deposited there on previous days.

Kidney-worm larvae were commonly found also among moist pine needles which covered the ground in the small pine groves usually included in the hog pastures in the locality under observation. It was observed that the hogs often spent the hotter portion of each day in these pine groves, resting and rooting among the pine needles. Consequently the situation in these places was somewhat similar to that on the feeding grounds, although the concentration of larvae was much lighter than on the feeding grounds.

Infective and preinfective *Stephanurus* larvae were recovered in small numbers from moist soil taken from shaded paths, from areas near trees, and from the vicinity of shaded wallows.

No larvae were recovered from either shaded or unshaded dry soil. Furthermore, no larvae were found on moist soil that had been exposed to the sun for a period of more than a few hours.

Infective *Stephanurus* larvae were rarely found on areas covered with forage, and then only on low-lying areas where the soil was continually damp.

Contrary to the opinions of Ross and Kauzal (*5*) and others concerning the importance of wallows in the dissemination of the swine kidney worm, these areas were found to be of comparatively little importance in this respect. This conclusion seems justified in view of the fact that infective *Stephanurus* larvae were recovered from wallows in only 22 of 472 examinations. Moreover, in 8 cases where infested animals were seen to urinate in wallows, Baermann examinations of mud and water from the entire areas, made twice a week for periods of 6 weeks, gave consistently negative results.

In this connection a comparison was made in two instances of the number of larvae recovered by means of the Baermann apparatus from measured quantities of mud and water taken from wallows, with the number of larvae recovered from known amounts of soil and husks from feeding grounds some distance away from these wallows. In each determination, 3 weekly collections were made of 2 quarts of soil and husks from the feeding ground and 2 gallons of mud and water from the wallow which was to be examined. In the first test a total of 4,567 *Stephanurus* larvae were recovered from the soil and husks taken from the feeding ground. In contrast to this, no larvae were found in the mud and water from the wallow. Similar results were obtained from the second test, 1,498 larvae being found in material taken from the feeding ground and none in that from the wallow.

Since *Stephanurus* larvae were not recovered from mud and water taken from wallows in the examinations described above, a series of tests was carried out to determine the fate of kidney-worm eggs and larvae when exposed experimentally to conditions which exist in wallows. In each of 4 tests, kidney-worm eggs and larvae were placed in a shaded wallow in a vacant hog pasture, and from 3 to 6 weekly examinations were made of mud and water from the entire wallow, by means of the Baermann apparatus. No larvae were recovered in any of the examinations.

These findings indicate that kidney-worm larvae die rather quickly under conditions present in wallows and that the wallow is evidently of minor importance in the spread of the swine kidney worm in the locality where this investigation was conducted.

The results of this series of observations on the distribution of kidney-worm larvae in hog pastures indicate that most kidney-worm infections in hogs are evidently acquired in a comparatively small number of places, namely the feeding grounds and shaded areas in pine woods. This finding has a bearing on control measures.

## LONGEVITY OF INFECTIVE KIDNEY-WORM LARVAE

Ross and Kauzal (*5*) reported that infective larvae of the swine kidney worm lived 154 days in a culture of soil and feces kept in the laboratory. They made no statement, however, as to the time such larvae would live under less favorable conditions outdoors. In order to obtain definite information on this point, the writer carried out two series of experiments. In the first series the larvae were kept in small experimental plots outdoors where variations in temperature occurred but where abundant moisture was supplied at all times. The second series was carried out under pasture conditions where the larvae were subjected to prevailing variations in temperature and moisture. The experiments in which the larvae were kept under favorable conditions as regards moisture, already briefly reported (*11*), are here reported in detail. Certain other experiments fully reported previously (*11*) dealt with the length of time larvae lived under experimental conditions when moisture was not supplied.

Kidney-worm larvae that had just reached the infective stage were placed on sterile soil in experimental plots kept under conditions approximating those commonly found in hog pastures of that locality. The experimental plots were laid out by first placing layers of gravel

in the bottoms of metal containers, such as deep pans or tubs, which were then filled with moist, sterile soil. This soil was kept moist by the addition of water through a pipe extending into the layer of gravel in the bottom of each container. Some of these containers were placed in the sun, and others in the shade. The soil in certain of the containers exposed to the sun was covered with a layer of corn husks, and in others a sod of carpet grass was grown. By the addition of large quantities of water the soil in some containers was made to resemble wallows.

The Baermann apparatus was used in examining the soil, daily examinations for larvae being made of soil samples from each plot. In order that the total number of larvae on any experimental area might not be materially reduced by the daily examinations, all the larvae recovered in the Baermann isolations were returned to the places from which they were taken. The next day soil for examination was taken from a different area in the experimental field. Whenever a sample of soil was negative for larvae, additional isolations were made from that plot until positive results were obtained or until it became apparent that all the larvae were dead.

Counts of the number of larvae recovered from the soil of the experimental areas were not made. However, in this connection it was observed that the number of larvae recovered in each isolation decreased progressively until, toward the end of the experiment, only one or two larvae were recovered in each isolation.

In table 1 are shown the periods during which kidney-worm larvae were recovered from the various types of experimental plots, together with the maximum and minimum air temperatures, and the number of cloudy days during those periods.[3]

TABLE 1.—*Periods during which experimental plots contained live Stephanurus larvae when adequate moisture was supplied*

LARVAE BENEATH CORN HUSKS AND OTHER DEBRIS, ON UNSHADED SOIL

| Date of beginning of test | Experimental plots used | Air temperature during longest period that larvae survived | | Cloudy days during longest period that larvae survived | Period during which live larvae were recovered | | |
|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | | Plot 1 | Plot 2 | Plot 3 |
| | *Number* | *° F.* | *° F.* | *Number* | *Days* | *Days* | *Days* |
| Apr. 4, 1930 | 3 | 91 | 49 | 48 | 50 | 60 | 65 |
| July 26, 1930 | 3 | 94 | 62 | 49 | 58 | 64 | 42 |
| Aug. 9, 1930 | 3 | 94 | 52 | 49 | 50 | 73 | 62 |
| Oct. 8, 1930 | 3 | 86 | 30 | 32 | 41 | 55 | 63 |
| Oct. 31, 1930 | 2 | 77 | 30 | 38 | 21 | 53 | ------- |
| Nov. 5, 1930 | 1 | 77 | 30 | 38 | 27 | ------- | ------- |
| Dec. 12, 1930 | 2 | 66 | 32 | 8 | 21 | 25 | ------- |
| Jan. 24, 1931 | 1 | 77 | 33 | 34 | 50 | ------- | ------- |
| Feb. 10, 1931 | 1 | 81 | 45 | 36 | 54 | ------- | ------- |
| Apr. 16, 1931 | 2 | 91 | 49 | 46 | 75 | 76 | ------- |

[3] The meteorological data were obtained from the U.S. Department of Agriculture Weather Bureau station at Thomasville, Ga., 28 miles southwest of Moultrie.

TABLE 1.—*Periods during which experimental plots contained live Stephanurus larvae when adequate moisture was supplied*—Continued

LARVAE ON SHADED SOIL

| Date of beginning of test | Experimental plots used | Air temperature during longest period that larvae survived | | Cloudy days during longest period that larvae survived | Period during which live larvae were recovered | | |
|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | | Plot 1 | Plot 2 | Plot 3 |
| | *Number* | *° F.* | *° F.* | *Number* | *Days* | *Days* | *Days* |
| Sept. 20, 1929 | 2 | 88 | 44 | 21 | 35 | 26 | ------- |
| Oct. 31, 1929 | 2 | 86 | 24 | 24 | 32 | 29 | ------- |
| Nov. 15, 1929 | 1 | 84 | 24 | 21 | 35 | ------- | ------- |
| Dec. 10, 1929 | 1 | 78 | 26 | 8 | 9 | ------- | ------- |
| Jan. 4, 1930 | 1 | 77 | 37 | 10 | 10 | ------- | ------- |
| Jan. 9, 1930 | 3 | 75 | 32 | 9 | 9 | 12 | 12 |
| Jan. 22, 1930 | 3 | 66 | 30 | 1 | 3 | 0 | 0 |
| Feb. 1, 1930 | 3 | 74 | 36 | 12 | 12 | 16 | 9 |
| Mar. 4, 1930 | 3 | 78 | 39 | 26 | 15 | 30 | ------- |
| Mar. 31, 1930 | 2 | 90 | 47 | 34 | 30 | 55 | ------- |
| Apr. 4, 1930 | 2 | 91 | 49 | 49 | 29 | 64 | ------- |
| Apr. 11, 1930 | 2 | 102 | 58 | 42 | 48 | 66 | ------- |
| July 26, 1930 | 2 | 94 | 62 | 32 | 39 | 43 | ------- |
| Aug. 9, 1930 | 2 | 94 | 52 | 49 | 55 | 63 | ------- |
| Oct. 14, 1930 | 1 | 89 | 35 | 18 | 30 | ------- | ------- |
| Oct. 31, 1930 | 1 | 77 | 33 | 16 | 19 | ------- | ------- |
| Nov. 5, 1930 | 2 | 77 | 37 | 19 | 15 | 20 | ------- |
| Nov. 12, 1930 | 2 | 73 | 30 | 13 | 15 | 15 | ------- |
| Nov. 18, 1930 | 2 | 73 | 30 | 6 | 8 | 7 | ------- |
| Nov. 26, 1930 | 2 | 58 | 30 | 0 | 1 | 1 | ------- |
| Dec. 3, 1930 | 1 | 70 | 32 | 11 | 15 | ------- | ------- |
| Dec. 12, 1930 | 1 | 66 | 32 | 9 | 11 | ------- | ------- |
| Dec. 24, 1930 | 1 | 63 | 32 | 8 | 9 | ------- | ------- |
| Jan. 15, 1931 | 1 | 50 | 29 | 0 | 1 | ------- | ------- |
| Jan. 27, 1931 | 1 | 74 | 30 | 9 | 15 | ------- | ------- |
| Jan. 30, 1931 | 1 | 74 | 30 | 6 | 12 | ------- | ------- |
| Mar. 16, 1931 | 1 | 84 | 36 | 27 | 38 | ------- | ------- |
| Apr. 29, 1931 | 1 | 100 | 41 | 25 | 60 | ------- | ------- |

LARVAE ON SOIL, IN SUN

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Oct. 31, 1929 | 3 | 86 | 40 | 6 | 0 | 0 | ------- |
| Nov. 15, 1929 | 2 | 84 | 24 | 0 | 0 | 1 | ------- |
| Dec. 10, 1929 | 2 | 74 | 46 | 1 | 0 | 0 | ------- |
| Dec. 11, 1929 [1] | 2 | 78 | 26 | 7 | 8 | 2 | ------- |
| Jan. 4, 1930 [1] | 2 | 77 | 26 | 12 | 14 | 15 | ------- |
| Do | 2 | 55 | 37 | 0 | 0 | 0 | ------- |
| Jan. 9, 1930 [1] | 2 | 75 | 26 | 8 | 10 | 0 | ------- |
| Do | 2 | 75 | 54 | 0 | 0 | 0 | ------- |
| Feb. 1, 1930 [1] | 1 | 74 | 34 | 11 | 16 | ------- | ------- |
| Do [1] | 1 | 72 | 43 | 6 | 7 | ------- | ------- |
| Mar. 31, 1930 [1] | 2 | 91 | 47 | 26 | 10 | 37 | ------- |
| Do | 2 | 74 | 47 | 0 | 0 | 1 | ------- |
| Apr. 11, 1930 [1] | 2 | 84 | 59 | 3 | 0 | 4 | ------- |
| Do | 2 | 82 | 58 | 2 | 2 | 0 | ------- |
| Aug. 9, 1930 [1] | 1 | 94 | 62 | 10 | 14 | ------- | ------- |
| Do | 1 | 94 | 72 | 2 | 3 | ------- | ------- |

LARVAE ON SOIL AT BASE OF CARPET GRASS, IN SUN

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Dec. 10, 1929 | 2 | 78 | 26 | 8 | 9 | 5 | ------- |
| Dec. 12, 1929 | 2 | 78 | 26 | 6 | 7 | 0 | ------- |
| Jan. 4, 1930 | 1 | 78 | 26 | 12 | 15 | ------- | ------- |
| Jan. 23, 1930 | 2 | 66 | 30 | 4 | 8 | 18 | ------- |
| Feb. 1, 1930 | 2 | 81 | 31 | 19 | 31 | 20 | ------- |
| Mar. 14, 1930 | 1 | 78 | 60 | 19 | 22 | ------- | ------- |
| Mar. 31, 1930 | 2 | 86 | 47 | 21 | 28 | 30 | ------- |
| Apr. 4, 1930 | 1 | 91 | 47 | 49 | 67 | ------- | ------- |
| Aug. 9, 1930 | 2 | 94 | 56 | 43 | 20 | 54 | ------- |
| Oct. 14, 1930 | 1 | 86 | 30 | 29 | 44 | ------- | ------- |
| Apr. 1, 1931 | 1 | 97 | 53 | 37 | 54 | ------- | ------- |

[1] The larvae were placed on loose, porous soil.

TABLE 1.—*Periods during which experimental plots contained live Stephanurus larvae when adequate moisture was supplied*—Continued

LARVAE OR EGGS IN MUD WALLOWS, IN SUN[2]

| Date of beginning of test | Experimental plots used | Air temperature during longest period that larvae survived | | Cloudy days during longest period that larvae survived | Period during which live larvae were recovered | | |
|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | | Plot 1 | Plot 2 | Plot 3 |
| | *Number* | *° F.* | *° F.* | *Number* | *Days* | *Days* | *Days* |
| Nov. 20, 1929 | [3] 1 | | | | | | |
| Dec. 10, 1929 | [3] 1 | | | | | | |
| Jan. 4, 1930 | 3 | 75 | 37 | | 2 | 0 | 2 |
| Jan. 10, 1930 | 3 | 70 | 56 | | 2 | 3 | 0 |
| Jan. 20, 1930 | [4] 2 | | | | | | |
| Jan. 26, 1930 | 2 | 66 | 47 | | 0 | 2 | |
| Feb. 7, 1930 | [4] 3 | | | | | | |
| Mar. 1, 1930 | 2 | 69 | 31 | | 1 | 4 | |
| Mar. 15, 1930 [5] | 1 | 74 | 60 | | 2 | | |
| Apr. 5, 1930 | 1 | 80 | 49 | | 3 | | |
| Apr. 10, 1930 | 2 | 81 | 55 | | 0 | 1 | |
| June 6, 1930 [5] | 2 | 83 | 67 | | 2 | 0 | |
| Do | [4] 2 | | | | | | |
| June 7, 1930 | [3] 1 | | | | | | |
| Aug. 9, 1930 [5] | 1 | 92 | 72 | | 1 | | |
| Do | [3] 1 | | | | | | |
| Aug. 12, 1930 | [3] 1 | | | | | | |

[2] Determinations were made on larvae, except when eggs are specified.
[3] Eggs recovered; no larvae.
[4] Preinfective larvae.
[5] No larvae recovered.

As is shown in table 1, when the larvae were protected from light and desiccation and, to a certain extent, from extreme variations in temperature by a covering of corn husks and other debris, the plots remained positive for larvae during a maximum of 76 days. Areas of moist, shaded soil remained positive during a somewhat shorter time, 66 days being the maximum time in which larvae were recovered under those conditions. In contrast to this, when larvae were placed on moist soil that was exposed to the sun, live larvae were seldom recovered after the first day. However, in one instance two larvae were recovered on the thirty-seventh day after the beginning of the experiment. In this case the soil was very loose and porous and may have afforded some protection to the larvae. It is to be noted also that in this test 26 of the 37 days were cloudy.

As is also shown in the table, when infective larvae were placed in small, artificially constructed wallows they apparently died rather quickly. In one instance larvae were recovered four days after the beginning of the experiment, after which time the plot remained negative. Preinfective larvae failed to reach the infective stage and eggs failed to hatch under these conditions.

As can also be seen from table 1, the periods during which the experimental plots described remained positive for larvae in winter were much shorter than the periods during which they remained positive in the warm months of the year. In every case, when the minimum temperatures dropped below freezing for a sufficient length of time to freeze the ground in the experimental plots, they became negative, the larvae apparently having been killed by the low temperatures.

These observations, which are in accord with the findings of Schwartz and Price (*8*) and of Ross and Kauzal (*5*), were confirmed by examinations of infested areas in hog pastures made by the writer during the winter months. As was found to be the case on the experimental plots, the larvae in hog pastures were readily killed by freezing.

In conjunction with these experiments, additional tests were made on the longevity of infective larvae under pasture conditions, in which the larvae were exposed to normal variations of temperature and moisture. These experiments were carried out during the spring and summer of 1931 on a carpet-grass pasture that had been unoccupied by hogs for more than a year. In each of five tests several thousand infective larvae were placed on areas of unshaded soil in this pasture and also among moist pine needles in an area of pine woods adjacent to the pasture. Weekly examinations were made, by means of the Baermann apparatus, of the areas on which the larvae had been placed and of the surrounding soil and debris. Table 2 shows the length of time the larvae lived under these conditions, together with the distances they migrated, the maximum and minimum air temperatures, the rainfall, and the number of cloudy days during each period.

TABLE 2.—*Length of time infective Stephanurus larvae lived and the distance they migrated under field conditions, 1931*

| Date of beginning of test | Experimental plots used | Air temperature during longest period that larvae survived | | Rainfall during longest period that larvae survived | Cloudy days during longest period that larvae survived | Period during which live larvae were recovered | | Greatest distance larvae migrated |
|---|---|---|---|---|---|---|---|---|
| | | Maximum | Minimum | | | Plot 1 | Plot 2 | |
| | *Number* | *°F.* | *°F.* | *Inches* | *Number* | *Days* | *Days* | *Inches* |
| LARVAE ON UNSHADED SOIL OF A CARPET-GRASS PASTURE | | | | | | | | |
| Feb. 27 | 1 | 74 | 34 | 2.13 | 18 | 24 | ---------- | 12 |
| Apr. 24 | 2 | 95 | 58 | .62 | 9 | 14 | 20 | 6 |
| May 14 | 2 | 97 | 56 | .54 | 12 | 12 | 18 | 10 |
| June 12 | 2 | 84 | 67 | 1.20 | 6 | 0 | 6 | 0 |
| July 7 | 2 | 94 | 70 | 2.19 | 9 | 0 | 9 | 0 |
| LARVAE AMONG MOIST PINE NEEDLES SHADED BY PINE TREES | | | | | | | | |
| May 14 | 2 | 97 | 68 | 1.00 | 23 | 18 | 29 | 0 |
| June 12 | 1 | 103 | 69 | 3.40 | 12 | 24 | ---------- | 0 |
| July 7 | 1 | 70 | 69 | 5.03 | 17 | 20 | ---------- | 0 |

Larvae were recovered from the pasture areas for periods of from 6 to 24 days, and from among pine needles for periods of from 18 to 29 days after the beginning of the experiments. These results indicate that when larvae of the swine kidney worm are exposed to the environmental conditions present in carpet-grass pastures and pine woods, they survive a shorter time than under the more favorable conditions of shade and abundant moisture.

## EFFECTS OF VARIOUS ENVIRONMENTAL CONDITIONS UPON KIDNEY-WORM EGGS AND INFECTIVE LARVAE

In order to account for the short time which infective *Stephanurus* larvae lived in unprotected situations as compared with the time they lived under more favorable conditions, a series of experiments was carried out in the laboratory to determine the effect of the various environmental factors upon these larvae. The effects of sunlight, desiccation, and high temperature upon infective larvae are discussed in this order.

### EFFECT OF SUNLIGHT ON INFECTIVE LARVAE

As was stated in discussing the results of the survey of hog pastures for larvae, no live kidney-worm larvae were recovered by the writer from either moist or dry soil that had been exposed to sunlight for more than a few hours. Furthermore, as shown in table 1, larvae lived a very short time on experimental plots exposed to the sun, even though abundant moisture was supplied at all times.

In order to account for this, the following experiment on the effect of sunlight upon kidney-worm larvae was carried out: 100 active infective larvae were placed in each of several 5-cc vials filled with water at a temperature of 77° F.; each vial was then suspended in a horizontal position in a 1-liter beaker by means of a wire stuck in the cork of the vial and looped over the rim of the beaker. Each beaker was then filled with water at a temperature of 77°, and the larvae in the vial-beaker set-ups were exposed to sunlight for varying periods over a white background, the water in the beakers being kept at a constant temperature throughout the period of exposure to sunlight. After this exposure, the larvae were kept in the dark for 24 hours at a temperature of from 68° to 77°. At the end of this time they were warmed to 98.6° to determine whether or not they were still alive. In each experiment an equal number of control larvae were exposed in the same manner to the diffuse light from a north window at 77° for the same length of time that the experimental larvae were exposed. All the control larvae survived under these conditions. In contrast to this, it was found in a series of experiments carried out during June and July 1931 that exposure to sunlight for a period of 1 hour on a clear day was sufficient to kill infective kidney-worm larvae. In agreement with the results obtained with the control larvae, an exposure of 9 hours to outdoor conditions on totally cloudy days was found insufficient to kill the larvae.

To test further the effect of sunlight upon these worms, infective larvae were placed on moist, hard-packed soil in Petri dishes. These dishes were then set in the sun. At each 1-minute interval a dish was removed to the laboratory, placed in water in a pan, with the level of the water below that of the soil in the Petri dish, and kept in the dark for 24 hours at a temperature of from 68° to 77° F. At the end of this time both the soil in the Petri dishes and the water in the pans were examined for live larvae.

In a series of 12 tests carried out on clear days during the months of June, July, and August, 15 minutes was the maximum period that larvae were found to survive under these conditions. These findings are supported by the results of field studies on the effect of sunlight upon the eggs and larvae of this parasite. On one of the farms under observation, a brood sow was confined in a farrowing pen from which all vegetation and debris had been removed. The sow habitually urinated on an area of soil close to the north side of a wooden gate. Because of the nature of the soil, this area was continually damp. Examinations were made of the soil twice a week for a period of 4 weeks, the length of time the sow was allowed to remain under these conditions. On three occasions, infective larvae were found on the soil shaded by the gate. In contrast to this, no larvae were recovered from the contaminated areas that were continually exposed to the sun.

These experiments and observations indicate that the larvae of the swine kidney worm are very susceptible to the action of sunlight

and are readily killed on moist soil that is exposed to sunlight. This accounts, in part at least, for the failure to find infective larvae on soil exposed to the sun, and also for the short periods during which larvae survived on unshaded experimental areas. (Table 1 and p. 7.)

#### EFFECT OF DESICCATION ON EGGS AND INFECTIVE LARVAE

Since, as stated in the results of the survey of kidney-worm-infested hog lots, kidney-worm larvae were never recovered from dry soil, a series of tests was performed to determine the effect of desiccation on the eggs and larvae of this parasite.

To determine the effect of desiccation on eggs, single drops of water, each containing approximately 300 eggs in the early stages of development, were placed in several places on a layer of dry pulverized soil indoors where the temperature varied from 68° to 77° F. At intervals of 15 minutes the soil containing the eggs from a single drop of water was removed, moistened, mixed with charcoal, and cultured for 10 days at room temperature (68° to 80.6°). The viability of the eggs in each test was determined by examinations of soil and charcoal cultures made from eggs not exposed to drying. The results of the 17 tests are given in table 3. These data show that kidney-worm eggs are killed by air-drying in from 7 to 10.75 hours.

TABLE 3.—*Effects of air-drying on kidney-worm eggs and infective larvae*

| Test no. | Time of survival | | Test no. | Time of survival | | Test no. | Time of survival | |
|---|---|---|---|---|---|---|---|---|
| | Eggs | Larvae | | Eggs | Larvae | | Eggs | Larvae |
| | *Hours* | *Hours* | | *Hours* | *Hours* | | *Hours* | *Hours* |
| 1 | 10.75 | 2.50 | 7 | 8.00 | 3.50 | 13 | 10.00 | ------- |
| 2 | 9.25 | 3.25 | 8 | 10.50 | 2.00 | 14 | 9.00 | ------- |
| 3 | 10.00 | 3.00 | 9 | 10.50 | 3.25 | 15 | 10.25 | ------- |
| 4 | 8.50 | 2.75 | 10 | 10.75 | 2.50 | 16 | 9.75 | ------- |
| 5 | 8.25 | 3.50 | 11 | 10.25 | 1.75 | 17 | 10.50 | ------- |
| 6 | 7.00 | 1.00 | 12 | 9.50 | 3.25 | | | |

In order to obtain additional information on this point a study was made, under field conditions, during the spring and summer months of 1931, of the effect of sunlight and desiccation on kidney-worm eggs that had been deposited by infested animals when urinating on dry, unshaded soil. Immediately after these animals had urinated, a portion of the soil on which the urine fell was collected and later taken to the laboratory, kept for varying periods, and then mixed with charcoal and incubated at room temperature. The location of the infested soil was carefully marked, and a second sample taken 24 hours later.

In a study of 62 such areas it was found that 24 hours after the urine had been deposited the soil was caked and dry. Eggs recovered by the salt-flotation technic from these areas appeared to be dead in all cases. When this soil was moistened, mixed with charcoal, and incubated at room temperature, no larvae were recovered from any of the 62 samples, even after an incubation period of 15 days. On the other hand, soil samples collected immediately after the urine was deposited yielded infective larvae, with but two exceptions, after 5 to 8 days' incubation.

Since it was found that *Stephanurus* ova are quickly killed by desiccation, a series of tests was made to determine the effect of air-drying

on the infective larvae of this parasite. In these tests infective larvae, in small drops of tap water, were placed on dry pulverized soil in the shade, where the temperature varied from 68° to 80.6° F. At intervals of 15 minutes, soil samples containing the larvae from a drop of water were removed and placed in the Baermann apparatus to determine whether or not the larvae were still alive. The results of the tests are shown in table 3.

During certain of these tests the larvae were still alive after 3 hours, even though the soil appeared to be dry. On microscopical examination it was found that each particle of soil was surrounded by a thin film of water and that it was only after this water had entirely evaporated that the larvae died. In view of this fact, much of the variation in the survival time, 1 to 3½ hours, can perhaps be attributed to the variation in the rate at which the water evaporated from the soil particles.

The results of these tests and observations of the effect of desiccation on kidney-worm eggs and larvae confirm the findings of Schwartz and Price (*8*) and of Ross and Kauzal (*5*) to the effect that these stages of the kidney worm are readily killed by drying. This susceptibility of the eggs and larvae to drying serves to explain the failure to find live kidney-worm eggs and larvae in places where they would be exposed to drying.

### EFFECT OF HIGH TEMPERATURE ON INFECTIVE LARVAE

No attempt was made to determine the maximum temperature at which infective larvae will live on soil, but in laboratory tests it was found that the infective larvae are killed almost instantly in water at a temperature of from 123.8° to 124.7° F.

## REACTION OF INFECTIVE KIDNEY-WORM LARVAE TO CERTAIN ENVIRONMENTAL STIMULI

### REACTION TO LIGHT

In order to determine the reaction of infective *Stephanurus* larvae to light, the following tests were performed.

Several hundred active infective larvae were placed in water in a glass tube which was stoppered at both ends. One half of the tube, placed in a horizontal position, was then inserted in a wooden thermometer case, and the opening around the tube plugged with cotton, leaving half of the tube in constant darkness and the other half exposed to daylight. The tube and thermometer case were then placed in a horizontal position on a table by a window, out of direct sunlight, and the position of the larvae in the tube was determined 4 days later. When a small portion of the covered end of the tube was pulled out, a large number of larvae were seen to have gathered at a point in the tube which had been just inside the mouth of the thermometer case. The majority of these larvae had apparently migrated from both the covered and uncovered portions of the tube to what was probably the point of most favorable light intensity for them.

Further, to test the reaction of infective kidney-worm larvae to light, several hundred active larvae were placed in a Petri dish approximately one fourth full of water, half the dish being covered with black paper. The dish was placed on a table near a north window, and the larvae were distributed in the dish as evenly as possible. When the dish was examined 3 days later, there was, as before, a noticeable grouping of larvae just inside the darker area.

These observations indicate that the infective larvae of the swine kidney worm are, to a certain extent at least, negatively phototropic. This condition, it seems, would enable larvae on soil to escape the destructive effects of sunlight by migrating for short distances into protected situations. In this manner many larvae would be able to survive in relatively dark places, whereas they might be destroyed in lighter areas.

### REACTION TO HEAT

When a hot needle was applied to the under side of a watch glass containing infective larvae in water it was found that those in the vicinity of the needle soon became active. When the process was continued for several minutes, the larvae for some distance away gradually migrated toward the point of greatest heat.

The reaction of infective kidney-worm larvae to heat was further tested by a method similar to that used by Mönnig (*1*). A large number of infective larvae were placed in a small glass tube of water which was stoppered with small corks. A copper wire of small diameter was wound several times around the middle of the tube, and the end of the wire was left projecting a distance of about 4 inches beyond the tube. The tube was placed in a horizontal position on the stage of a microscope, and heat was applied to the end of the wire by means of an alcohol lamp, care being taken not to apply the heat so rapidly that bubbles would be formed and currents set up in the water. As the heat penetrated along the column of water the larvae became quite active. As the water became warmer, many of the larvae for a distance of an inch or more on each side of the wire began to migrate slowly toward the warmest spot. In about an hour many of these larvae had collected near the wire at the point of greatest heat, which indicates that the larvae are positively thermotropic with respect to degrees of heat likely to be encountered under natural conditions.

## MIGRATIONS OF INFECTIVE KIDNEY-WORM LARVAE

### LATERAL MIGRATION ON MOIST SOIL

In order to determine whether infective *Stephanurus* larvae migrate extensively over the surface of the soil, the following tests were carried out. Infective larvae were placed on narrow strips of shaded soil each of which was bounded on all sides by pieces of dry tin, soldered at the corners and extending 2 inches above and 2 inches below the surface of the soil. Moisture was supplied, as previously described, by means of a pipe extending to the bottoms of the containers in which the tests were performed. The results of the tests are shown in table 4.

TABLE 4.—*Extent of lateral migration of infective kidney-worm larvae*

| Test no. | Distance the larvae migrated | Time | Test no. | Distance the larvae migrated | Time | Test no. | Distance the larvae migrated | Time |
|---|---|---|---|---|---|---|---|---|
| | *Inches* | *Days* | | *Inches* | *Days* | | *Inches* | *Days* |
| 1 | 3 | 9 | 3 | 4 | 12 | 5 | 2 | 12 |
| 2 | 3 | 5 | 4 | 2 | 30 | 6 | 3 | 51 |

As may be seen from table 4, very little lateral migration occurred under these conditions. In this connection it should be noted, however, that considerable lateral movement of larvae occurred (12 inches in one case) in three of five tests on the longevity of infective larvae under pasture conditions. (Table 2.) In these instances however, heavy rains had occurred during the time the tests were in progress, which accounts, perhaps, to a certain extent at least, for this movement.

### VERTICAL MIGRATION THROUGH MOIST SOIL

In order to determine whether or not infective kidney-worm larvae are able to migrate upward through soil, three tests were performed, as follows: Several hundred infective larvae were placed in the bottoms of each of four small tin cans about 2½ inches deep, which were then filled with moist sterile soil. Each can had a number of holes punched in the sides near the top to permit the entrance of moisture to the soil inside the can. These containers were then placed in a tub of sterile dirt with the surface of the soil in the cans slightly above that in the tub. Moisture was supplied to the soil in the tub in the manner previously described. Daily examinations for larvae were made over a period of 3 weeks, both the surface soil in each can and the dirt in the tub being examined. After each examination an amount of sterile soil equal to that used in the examination was returned to each can.

In these tests only a few larvae were found to have reached the surface of the soil in the cans at any time during the periods in which the examinations were made. In the first series of examinations 1 larva was recovered from the surface of the soil in a can on the fourteenth day, and 3 from another can on the fifteenth day; in the second series, 1 larva was found on the tenth day; and in the third series 4 larvae were recovered from the surface of the soil in a can on the eleventh day.

No larvae were recovered from the soil in the tubs, outside the cans, at any time; this indicates that the larvae did not migrate to the soil outside the cans.

Since some vertical migration of infective larvae occurred under experimental conditions, a series of examinations was made of kidney-worm-infested fields, both before and after plowing, to determine whether vertical movement of larvae through soil occurs under these conditions.

Shortly before the fields under observation were plowed, a number of infested spots were carefully located; after plowing, six weekly examinations were made, by means of the Baermann apparatus, of the soil directly over and for some distance around the spots where the larvae were buried by the plow; no larvae were recovered from the soil taken from any of the 95 areas examined. As was the case under experimental conditions, apparently the larvae showed very little tendency to move upward through soil, either by their own efforts or by the capillary movement of water contained in the soil. The depth to which a plow would bury larvae exceeds 2½ inches; and either the percentage of larvae that could migrate upward a distance distinctly greater than 2½ inches was very small, or the distance was too great for any larvae to migrate.

These results confirm the findings of Ross and Kauzal (*5*), to the effect that extensive vertical migration of kidney-worm larvae through

soil apparently does not occur. The results also indicate that plowing of infested land is a control measure for this parasite.

### VERTICAL MIGRATION ON GRASS

Infective kidney-worm larvae were placed on soil in an experimental plot on which was a heavy sod of grass approximately 12 inches in height. Several times each day a number of stems of grass were cut close to the ground and divided into 1-inch lengths, measuring from the bottoms of the stems. The various 1-inch lengths of grass were then washed in separate dishes of warm water which was allowed to settle, following which the supernatant fluid was pipetted off and the residue examined for larvae. The various lengths of these samples of grass were also examined for larvae by means of the Baermann apparatus in the manner previously described.

Before or just after sunrise each morning, when the grass was wet with dew, large numbers of active kidney-worm larvae were recovered from the stems and blades of grass cut at that time, 2 inches being the maximum height at which larvae were found. After the dew had evaporated, however, only a few dead larvae were ever recovered from the grass. On the basis of the number of live larvae recovered before and after the dew had evaporated, and the results of experiments on the reaction of *Stephanurus* larvae to light, it may be concluded that as the grass blades dried the larvae migrated downward to the damp, shaded soil below. Some, however, were killed on the grass, either by the action of light from the sun or by desiccation, as the finding of dead larvae there proved.

The results of these experiments were confirmed on several occasions by the finding of live infective larvae on grass that had been cut from infested pastures before sunrise, whereas grass cut from the same areas after it had dried was always negative. Schwartz [4] found that kidney-worm larvae in charcoal-feces cultures kept in glass containers migrate up the sides of the containers and move in the films of moisture which settle on the walls of the glass vessels. He found that the larvae accumulate on the walls of the vessels in large clusters and wriggle very actively as long as moisture is present.

The upward migration of kidney-worm larvae on grass undoubtedly has a bearing on the dissemination of this parasite. In the locality in which this study was made, heavy dews fall almost every night, and hogs grazing early in the morning undoubtedly pick up many larvae which have migrated up the grass blades. This habit of the larvae, of ascending vegetation, may also explain the frequent occurrence of this parasite in the livers of cattle in this section of the United States.

## EFFECT OF GROWING CROPS ON LAND INFESTED WITH KIDNEY-WORM LARVAE

In order to determine whether the growing of a crop on an infested field would destroy the kidney-worm larvae present there, and thus enable the farmer to place clean animals on this land without danger of infestation, the following tests were made.

Infested areas in fields were carefully located immediately before the fields were plowed. After the land had been plowed, weekly examinations of the surface soil plowed over the infested spots were made

[4] Personal communication.

throughout the period of growth of the crop. Furthermore, collections of soil from these areas were made within a few minutes after the land was plowed for the next planting. In this manner examinations were continued, over a period of 18 months, of infested fields on which crops of corn, cotton, peanuts, tobacco, melons, sweetpotatoes, oats, and sugarcane were being grown. No larvae were found at any time; this indicates that plowing infested land and growing a crop on it will free the land of kidney-worm larvae and render it suitable for the raising of pigs free from kidney-worm infestations, if the breeding stock is unparasitized and if extraneous sources of contamination can be avoided.

## BASIS FOR CONTROL MEASURES

Suggestions for the control of the swine kidney worm have been made by Shealy and Sanders (*10*), Schwartz (*6*, *7*), Roberts (*4*), Ross and Kauzal (*5*), and others, all of whom emphasized the importance of maintaining sanitary conditions in hog lots as an initial step in the control of this parasite. Roberts (*4*) and Ross and Kauzal (*5*) further state that if control is to be accomplished it is important to take advantage of the susceptibility of kidney-worm eggs and larvae to the destructive effects of sunlight and desiccation by raising young pigs on clean, dry, well-drained soil that receives the maximum of sunlight. These writers also emphasize the desirability of plowing and working land on which infested animals have been kept before placing clean animals on it.

On the basis of the experimental data reported in this bulletin and of the results obtained by other workers, the following recommendations are made which embody the essential requirements for control of swine kidney worms.

A field that is used for farrowing purposes should be well drained and should have had at least one crop grown on it since last being used by infested animals. In view of the susceptibility of the eggs and larvae of this parasite to the destructive effects of sunlight and desiccation, farrowing houses, feeding pens, and water barrels should be located close to the fence on an area of dry, well-drained, unshaded soil at least 30 feet wide. This strip of soil should be kept free from vegetation and debris of all kinds. By this arrangement the sows will have to cross the strip of bare soil after leaving the feeding pens, farrowing houses, or water barrels, before reaching the grazing crop used as a source of green feed for the sows and pigs. As a result much of the urine passed by the sows at such times will fall on the bare unshaded soil where the kidney-worm eggs will be killed by sunlight and desiccation. Likewise, in view of the fact that swine habitually make paths along fences, a strip of bare soil 5 feet wide that is kept free from debris and vegetation should extend along the other sides of the farrowing field.

It is desirable that the sows be fed and watered in a pen to which the pigs are not admitted at any time. This pen should be located on the wide strip of bare soil. The sows should remain in the pen for at least 1 hour at each feeding time in order that most of the urine and feces they pass at feeding time may be in a place inaccessible to the pigs.

As soon as the pigs are old enough to eat, a balanced diet should be provided for them in self-feeders located in a creep on the wide strip of bare soil previously mentioned.

After the pigs have been weaned and transferred, by hauling, to clean ground, the old farrowing field should be plowed and at least one crop grown on it before it is again used for clean animals. Nighbert and Connelly (*3*) also recommended such a procedure.

Additional suggestions for the protection of pigs from kidney worms, based on the life cycle of the parasite, have been given by Schwartz (*7*). Details of management are also under further investigation on farms in the vicinity of Moultrie, Ga.

## SUMMARY

In a survey of kidney-worm-infested hog pastures in the vicinity of Moultrie, Ga., larvae of these worms were found almost entirely on moist, shaded soil where they were protected from light and desiccation. The greatest concentration of larvae was found to occur beneath piles of corn husks, cobs, and other debris, on areas where hogs were fed. Larvae were found less frequently among moist pine needles, on moist, shaded paths, and beneath grass on low-lying pasture areas. On the other hand, live larvae were never recovered even from moist soil when the soil had been exposed to sunlight for more than a few hours. Larvae were not recovered from dry soil at any time during this investigation.

Contrary to the findings of Ross and Kauzal in Australia, kidney-worm larvae were seldom recovered from wallows in the vicinity of Moultrie, Ga.

The maximum length of time infective larvae survived under favorable moisture conditions was found to be as follows: On experimental plots covered with corn husks and other debris, 76 days; on soil covered with growing grass, 67 days; on shaded areas, 66 days; on unshaded soil which was loose and porous, 37 days; in wallows, 4 days; on unshaded areas of bare packed soil, 3 days.

Under actual pasture conditions, live larvae were recovered from carpet-grass pastures for a maximum period of 24 days, and from pine needles in a pine grove for a maximum period of 29 days.

Kidney-worm larvae were found to be susceptible to low temperatures, being killed by freezing, both in experimental areas and under field conditions.

Infective kidney-worm larvae in water were killed by 1 hour's exposure to sunlight at 77° F. When exposed to sunlight on moist, smooth soil, infective larvae were killed in 15 minutes. These results were confirmed by the failure to find larvae on moist soil in hog lots exposed to sunlight.

Kidney-worm larvae and eggs were killed by desiccation on dry soil in the shade under experimental conditions, and evidently died under such conditions in the field.

Infective *Stephanurus* larvae were killed almost immediately by water at a temperature of from 123.8° to 124.7° F.

The results of experiments on the reaction of infective kidney-worm larvae to strong light suggest that these larvae avoid intense light, since they were found to migrate short distances away from strong light into light of slight intensity.

These larvae were also found to be positively thermotropic, being definitely attracted to moderately warm areas, into which they moved from colder areas.

Under experimental conditions infective larvae migrated laterally a maximum distance of 4 inches on moist soil. Under field conditions some lateral movement of larvae over soil was found to occur, 12 inches being the maximum distance recorded. Under experimental conditions a small number of larvae migrated vertically through 2½ inches of moist soil. These findings are in agreement with those of Ross and Kauzal (*5*), who found that these larvae would migrate vertically only a short distance through soil. From a study of infested fields no evidence was found which would indicate that infective larvae are able to migrate to the surface of soil after being covered to usual plowing depths.

Vertical migration of infective larvae on grass to a distance of approximately 2 inches was found to occur, both under experimental and field conditions when the grass was wet with dew.

In a study of kidney-worm-infested fields, extending over a period of 18 months, it was found that growing a crop on an infested area will apparently free the fields of the larvae present there.

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TECHNICAL BULLETIN No. 404 MAY 1934

# THE EXTERNAL ANATOMY OF THE RED DATE SCALE PHOENICOCOCCUS MARLATTI COCKERELL, AND ITS ALLIES

BY

F. S. STICKNEY

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*Bureau of Entomology*

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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Technical Bulletin No. 404 May 1934

UNITED STATES DEPARTMENT OF AGRICULTURE
WASHINGTON, D.C.

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By F. S. STICKNEY [1]

*Associate entomologist, Division of Fruit Insects, Bureau of Entomology*

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## INTRODUCTION

The relationships of *Phoenicococcus marlatti* Cockerell, one of the two best-known scale-insect pests of the date palm, have been obscure. None of its relatives had been definitely determined, and little could be said beyond the fact that it did not belong within any one of a number of recognized groups. With the object of possibly discovering definite relatives of this insect, the writer undertook the study of a wide variety of material. Eleven species were found that gave strong evidence of being related to it, and they are of further interest because, so far as is known, they occur only on species of palms or of the genus *Pandanus*, which is considered by plant morphologists to be of the primitive stock from which palms arose.

[1] The writer wishes to thank G. F. Ferris, of Stanford University, in whose laboratory this work was done, for his constant interest and many helpful comments, as well as for the privilege of using his laboratory and material and the facilities of the Stanford collection of Coccidae. He gratefully acknowledges his indebtedness to E. E. Green, of Camberley, Surrey, England, who sent him much valuable material. He is also indebted for a number of useful species to E. O. Essig, of the University of California, to E. M. Ehrhorn and L. A. Whitney, both of Honolulu, to W. J. Hall, formerly Government entomologist of Egypt, and to Frederick Laing, of the British Museum. In addition, valuable material was available from the U.S. National Museum collection of Coccidae. R. E. Snodgrass, of the Bureau of Entomology, kindly responded to a request for his opinion on body segmentation.

None of the 11 apparent relatives of *Phoenicococcus marlatti* is known to occur in this country, but since they are widely scattered through the tropical and subtropical belts of the world and are subject to a considerable variety of climatic conditions, it seems likely that one or more of them might be able to establish themselves as pests either of the date palm or of some of the other palms so freely utilized as ornamentals in the United States.

These 11 species, with *Phoenicococcus marlatti*, form a group that apparently can be segregated from all other coccids. By way of acknowledging the distinctiveness of this group of species, and incidentally for convenience in referring to them, the tribe Phoenicococcini is erected for the reception of the genera in which the members of the group are separated. This new tribal name is based on the first (as far as known) species described, *Phoenicococcus marlatti* Cockerell, and is of further interest in that its basic meaning, "of the palm", refers nicely to these insects which, as has been mentioned, are restricted to palms or palmlike plants.

In the course of this investigation some other coccids were observed that had a number of structural features very similar to the corresponding parts of members of the Phoenicococcini. In fact, a few of these forms seemed to possess no characteristics fundamentally at wide variance with those present within this tribe. Furthermore, some diaspine species, in their general characteristics, are so strikingly like the Phoenicococcini that they are considered as definitely allied to the latter. It is therefore proposed tentatively to place the Phoenicococcini within the diaspine assemblage. If the coccids are considered as a superfamily—a recent way of regarding them—then the diaspines will have to be raised to family rank; and to maintain a proper balance in this scheme of classification, the new subfamily Phoenicoccoccinae within the family Diaspidae must be erected to receive the tribe.

The above-mentioned considerations seemed to justify making a detailed study of the external anatomy of *Phoenicococcus marlatti* and its 11 apparent relatives, and figuring and discussing those parts of some other coccids that appeared to throw light on their relationships to the Phoenicococcini.

## ILLUSTRATIONS

Except in the case of *Phoenicococcus marlatti*, this study was made from dried specimens, all (including *P. marlatti*) prepared and mounted on slides, and for the most part in a rather flattened condition; also, in the preparation of most of the material it proved well nigh impossible to prevent a certain amount of wrinkling or other distortion. However, in many cases a satisfactory quantity of material was available from which to make comparisons and gain an idea of the actual condition of the parts. It should be borne in mind that some variation in size, form, position, or occurrence almost always exists in a structure, especially in one newly appearing or in process of disappearing. Nevertheless, it is believed that the determination of the typical situation as regards the various parts was in the main approximately accomplished. As far as possible, all figures were drawn from what were considered to be typical specimens, but no assurance is implied that the parts have been represented precisely true to the actualities.

Unless otherwise specified, all the divided drawings showing a complete half of the dorsal and ventral surfaces were made from young individuals. All structures within the limits of each individual drawing and all detached representations of corresponding structures in the same group of drawings were drawn to the same scale. For data on measurements and examples of variations occurring in structures, the reader is referred to the sections on comparative morphology and classification.

Within the limits of each figure all structures, except insignificant dermal markings and parts of the head-skeleton assemblage and rostrum, are either indicated, usually by a full representation, or discussed in the text. The head-skeleton assemblage and rostrum are figured rather incompletely in most instances and are left largely undiscussed, since they appear to be of the same general character in all species and give no evidence of being appreciably different from the corresponding parts treated in detail in another paper.[2] The designation and labeling of the parts in the separate drawing of a section of the head skeleton (fig. 12, *G*) is according to the system used in this other paper.

For the type species, *Phoenicococcus marlatti* and *Palmaricoccus attaleae*, full figures, showing a complete half of the dorsal and ventral surfaces, have been drawn of all post-embryonic stages except the prepupa of the latter, and, for the type species of the remaining genera of this group of apparent relatives of *P. marlatti*, of at least the first stage and the second and adult female stages. It is believed that the character of the structures of the stages omitted can be learned from the text and from an examination of corresponding figured parts of other species. The drawings for other coccids are limited largely to such parts as show comparisons of interest and possible significance between these coccids and those of the Phoenicococcini.

The segmentation of the body is based on an interpretation by R. E. Snodgrass, of the Bureau of Entomology, who gave as his opinion, after examining the adult male of *Phoenicococcus marlatti*, that the spiracles are borne by the anterior sections, and the legs by the posterior sections, of the thoracic segments; also that the metathoracic legs are so situated as to have crowded out in this region the first abdominal segment. Frequently two or more sections of the thorax are apparently fused or only partially indicated by sutures. Only one metathoracic segment is ever indicated on the dorsum, and it appears to be a continuation of the anterior section of the metathorax occurring on the venter; but it is considered here simply as the entire metathorax on this surface; also it was impossible to determine where the first abdominal segment ends and the posterior section of the metathorax begins. For convenience only the lateral margin is taken as the dividing line between different segments of the dorsum and the venter. Thus, two pairs of setae occurring fairly close together along the margin, one apparently just on the dorsal surface, the other just on the ventral surface, are considered as belonging to the segment or segments indicated by their locations. Difficulty is frequently encountered in determining the marginal line by which to separate the dorsum from the venter.

[2] STICKNEY, F. S. THE EXTERNAL ANATOMY OF THE PARLATORIA DATE SCALE, PARLATORIA BLANCHARDI TARG.-TOZZ., WITH STUDIES OF THE HEAD SKELETON AND ASSOCIATED PARTS. *In preparation.*

In order to make the body outline symmetrical, marginal structures, such as eyes, basal antennal segments, and bulges in the body derm, have been duplicated on both sides of divided drawings, but in no case have pores or setae been duplicated. The solid lines indicating the spiracular sclerites have been so drawn as to reveal their characteristics, though these sclerites, except when invaginated, are considered to be always just beneath the surface.

Many of the parts have been labeled, mainly to indicate apparent homologies through the various stages. The setae especially have been designated according to certain groupings. While no certainty is implied that the labeling always conforms strictly to the facts concerning homologies, it at least calls attention to the presence of the parts involved.

## ABBREVIATIONS AND SYMBOLS USED ON ILLUSTRATIONS

*a, b, c, d, e, f, g, h, i*, homologous setae on posterior segment
1*ab*–9*ab*, first to ninth abdominal segments
8*aba*, 9*aba*, eighth or ninth abdominal segment of adult male
*ai*, apparent invagination
*al*, alimentary tube
*ames*, anterior section of mesothorax
*amet*, anterior section of metathorax
*an*, antenna
*arp*, anal-ring pore
*ars*, anal-ring seta
*as*, anus
*av*, anal valve
3*b*, third bar
*ba*, basal segment of antenna
*bb*, basal bar
*bcla*3, boundary clear area of third instar
*bp*, boundary of pocket
*bpl*, base of salivary plunger
*bpen*, base of penis
*brs*, basal rostral seta
*brt*, brush of tracheoles
*bs*, basal sclerite
*bu*, bulla
*bw*, body wall
*bw*3, body wall of third instar
*bw*4, body wall of fourth instar (adult female)
*ca*, clear area
*cam*, clear area of metathorax
*cdp*, caudodorsal pore
*ch*, sclerotic area of head
*cha*, channel
*cla*, claw
*cm*, connecting membrane with developing subsequent instar
*cn*, condyle
*co*, coxa
*cp*, caudal projection
*cru*, crumena (pouch to accommodate rostralis)
*cst*, clear spot of trochanter (probably sensory)
*da*, dark area, probably vestigial pores
*db*, distal bar
*dba*, dorsal band
*df*, differentiated area
*dms*, dorsomarginal seta
*drs*, distorostral seta
*ds*, distal sclerite
*dsp*, dorsosubmarginal pore
*ee*, eye
*eo*, external opening
*eps*, empty pore spot
*fe*, femur
*fs*, frontal seta
*gsh*, genital sheath
*hs*, head skeleton
*ina*, invagination apparently of alimentary tube
*in*9*ab*, mouth of invagination of ninth abdominal segment
*inf*, intersegmental furca
*inr*, invagination of rostrum, or rostral slit
*ins*, invaginated seta
*it*, inner thickening of seventh abdominal segment
*la*, line of apposition of dorsal and ventral surfaces
*ld*, ledge of seventh abdominal segment
*le*, leg
*lmes*, lateromesal seta
*lp*, large pore
*ma*, body margin
*map*, marginal protuberance
*mav*, mouth of anal valve
*me*, mesal line
*mea*, meatus
*mep*, mesal pore
*mes*, mesal seta
*meso*, mesothorax
*meta*, metathorax
1*mhs*–4*mhs*, first to fourth mesal head setae
*mlp*, mesal limit of papillae
*mn*, mandible
*mns*, mandibular sheath
*mr*, membranous area through which rostralis of adult is forced
*mrs*, mesal rostral seta
*ms*, mesal sclerite
*mss*, mesothoracic spiracle

*mts*, metathoracic spiracle
*mv*, margin of anal valve
*mx*, maxillae
*mxt*, maxillary tendon
*oe*, esophagus
*os*, outline of corresponding structure in subsequent stage
*p*, pore
*pa*, papilla
*pen*, penis
*pgl*, pygidial lobe
*ph*, pharynx
*phs*, pharyngial sheath
*pl*, plate or squamula
*plw*, pharyngial lateral wall
*pmes*, posterior section of mesothorax
*pmet*, posterior section of metathorax
*pp*, pore spot containing pore
*pr*, prothorax
*psc*, pleural sclerite
*pt*, partition
*pte*, pharyngial tendon
*qp*, quinquelocular pore
*r*, rostrum
*rc*, rectum
*rop*, adult rostralis puncture
*ros*, rostralis, or mouth-stylets tube
5*s*–11*s*, fifth to eleventh homologous head setae
*sad*, salivary duct
*sap*, salivary pump
*sat*, salivary tendon
*sdc*, salivary-duct chamber
*se*, seta
1*se*–14*se*, first to fourteenth homologous antennal setae
*sep*, seta (in part)
*sip*, dorsal, slightly invaginated, simple pore
*slp*, spinelike process (probably seta)
*smp*, small pore
*sp*, spiracle
8-*sp*, 8-shaped pore
*spa*, spiracularia (spiracular sclerite)
*srs*, spinelike rostral seta
*ss*, submarginal seta
*ssg*, probably sensory spot of genital armature
*ssl*, sensory spot of legs
*sta*, slightly thickened area
*t*, trachea
*ta*, tarsus
*tc*, tracheal collar
*tch*, tracheal chamber
*te*, teeth of seventh abdominal segment
*ti*, tibia
*tm*, tracheole mass
*tn*, tendon
*tr*, trochanter
*trp*, trilocular pore
*tpl*, tendon of salivary plunger
*va*, vagina
*vms*, ventromarginal seta
*vu*, vulva
*xs*, extra seta (above greatest number in any preceding instar)
*xx*, may be absent

| | |
|---|---|
| Dots | Internal or underneath parts |
| Fine lines | Sclerotic |
| Long dashes | Probable location of suture |
| Long dashes and dots | Mesal limits of papillae |
| Short dashes | Ridge |
| Short dashes and dots | Depression |
| Stippling | Membranous |

## HOST PLANTS AND GEOGRAPHICAL DISTRIBUTION

As far as is known, *Phoenicococcus marlatti* and each one of its apparent relatives is restricted to a single genus of palms or to *Pandanus* alone. The records of their host plants are meager, however. Three of the species are listed as occurring simply "on palm", and another as occurring on "rottang", which probably refers to the genus *Calamus*, the prevailing creeper palm of the locality in which this species was collected, but possibly to *Daemonorops*, or perhaps even to some other genus.

*Phoenicococcus marlatti* has been taken from 3 species of *Phoenix*, *Palmaricoccus pritchardiae* from 2 species of *Pritchardia*, *Thysanococcus pandani* from 3 and possibly 4 species of *Pandanus*, and *Thysanococcus squamulatus* possibly from 2 species of *Calamus*. The records for the remaining 8 species give no indication of other than single host species for each.

The number of species now known are too few, and their host records too meager, to warrant any definite statements concerning the comparative interrelationships of insect and host.

This group of insects, in view of the fact that they number only 12, are unusually widely scattered through the tropical and subtropical

regions of the world, and no record has been found of their occurrence elsewhere. *Phoenicococcus marlatti* is found wherever date palms are commercially cultivated—in eastern Asia, North Africa, and the southwestern part of the United States—except in a few isolated oases. Besides from the date palm, *Phoenix dactylifera* L., it has been taken from *P. canariensis* (Hort.) and *P. reclinata* Jacq. in southern California, the location and history of these palms indicating that the insect spread to them from infested date palms established in the immediate vicinity. The following list gives the names of the 11 species associated with *Phoenicococcus marlatti*, their host plants, and the general geographical locations where they were found:

*Palmaricoccus*, new genus

*attaleae*, new species.—On *Attalea cohune* Mart., State of Colima, west coast of Mexico.

*pritchardiae*, new species.—On *Pritchardia hardyi* Rock, Molokai Island, Hawaii; on *P. rockiana* Becc., Punaluu, Oahu Island, Hawaii.

*nesiotes* Laing.—On "palm sp.", Lord Howe Island (between Australia and New Zealand); on "palm", Macheno, Hawaii.

*Halimococcus* Cockerell

*lampas* Cockerell.—On "palm", Natal, South Africa.

*thebaicae* Hall.—On doum palm, *Hyphaene thebaica* Mart., Egypt.

*borassi* Green.—On Palmyra palm, *Borassus flabellifer* L., Peradeniya, Ceylon.

*Platycoccus*, new genus

*tylocephalus* new species.—On "palm", Honolulu, Hawaii.

*Thysanococcus*, new genus

*chinensis*, new species.—On *Calamus* sp., Yenping, South China.

*pandani*, new species.—On *Pandanus* sp. and *P. tectorius* Soland., in both cases from Buitenzorg, Java; on *P. utilis* Bory and *P. penangensis* Ridley, in both cases from Singapore.

*squamulatus*, new species.—On *Calamus tetradactylus* Hance, Canton Christian College, Kwangtung, China; on "palm tree", Hong Kong, China.

*calami*, new species.—On *Calamus* sp. and on "rottang" (creeper palm of the tropical forest), in both cases from Buitenzorg, Java.

It is of interest to note that, of these 11 species, only *Palmaricoccus nesiotes* can be said to have been taken from well separated localities. Considering the wide distribution of such a few related species, it is probable that many others will eventually come to light. That other species have not now been recorded seems to be due chiefly to their restricted host range.

## COMPARATIVE MORPHOLOGY

With a few exceptions the terms used in discussing the external anatomy of the insects included in this bulletin are in common usage among coccidologists, or words of well-known meaning have been applied in the belief that their implications, in the connections in which they are employed, will be readily grasped. The few exceptions are "bulla", "spiracularia", "crumena", "rostrum", and "rostralis", all taken from MacGillivray (*12*) [3] (but not all original with him) and used for their apparent advantage in expressing briefly and precisely the parts referred to.

[3] Italic numbers in parentheses refer to Literature Cited, p. 162.

## EGG

The derm of the egg is a delicate membrane, which crumbles to a misshapen mass after the nymphs hatch and, in the puparial forms, is left within the puparium, where, in all observed cases, the eggshells are scattered about. In the available material the egg of all members of each genus possesses a single spine, two disconnected spines, or a single group of more or less closely bunched spines, in every case situated on the mesoventral surface or the mesocephalic margin of the head. The character of the spines can segregate satisfactorily only one genus (*Platycoccus*) from all the others.

## FIRST STAGE [4]

### WAX

The wax produced is normally white in color and cottony or filamentous in texture, though it may become matted down when old or if the individual is in a closely confined space, and it may take on a creamy or pale yellowish tinge. As observed in dried specimens, wax is absent or scarce and is located typically around the body margin, or it may more or less cover the body. In *Phoenicococcus* and *Palmaricoccus* it tends to be more in evidence than in the other genera. It never assumes any distinct formations. In the living individuals of *Phoenicococcus marlatti* it is generally fluffy when the insect is not confined, but otherwise it tends to become sufficiently dense practically to conceal the body.

### SHAPE AND SIZE OF THE BODY

In outline the body is usually elongate elliptical. In cross section it is typically rather flat at first and may be noticeably so. Older specimens show a tendency toward a plane surface beneath and a very slight to a roundish convexity above, especially in the wholly puparial [5] stages.

The size of the body, based on the average specimen in each species, varies about as follows: Newly hatched, 0.22 mm long and 0.12 mm wide, to 0.36 mm long and 0.20 mm wide; fully developed, 0.29 mm long and 0.20 mm wide, to 0.82 mm long and 0.39 mm wide. In fully developed individuals the females may or may not be appreciably larger than the males, the greatest difference in size occurring where the latter are wholly puparial, but the females are never normally smaller than the males. Males wholly puparial may be but little larger than the newly hatched specimens, but the greatest disparity in size between young and old individuals occurs in a partially puparial form. The size of the body may be of diagnostic value. For example, the widest range in size of young individuals occurs between two species in one genus, and their difference in size remains sufficiently great for it to be used satisfactorily in separating them. On the other hand, the body may be very nearly of the same size in species of different genera.

[4] A structural differentiation of sex was not observed in any species.

[5] Strictly speaking, "puparium" refers to a larval skin within which the pupa develops. It has, however, been used in a loose sense to include the skin of any instar entirely enclosing subsequent instars. For lack of a better term, it is so used in this bulletin.

## BODY DERM

In the term "body derm" are included segmentation, sclerotization, and such sculpturing as papillae, spines, spicules, and other characteristic dermal markings. The segmentation may be almost complete,[6] failing only on the ventral surface cephalad of the posterior section of the mesothorax, or it may be largely obscure except on the abdomen, where it is always at least partially in evidence.

The body may be considered as membranous in the younger individuals, except that in *Phoenicococcus* and *Palmaricoccus* certain sclerotic areas may be present in the vicinity of the head skeleton as well as caudad of the rostrum and on the posterior abdominal segment, or in addition the penultimate segment may be moderately sclerotic, this sclerotization frequently extending in a decreasing degree cephalad onto the next segment or two. There is a general sclerotization of the body as the instar matures, typically less marked on the venter than on the dorsum. Papillae and definitely recognized spines are absent. Spicules occur most freely on the ventral surface of the thoracic segments caudad of the rostrum in numerous more or less irregular rows. Spicules are considered to be merely a form of dermal thickening, and if numerous give a sclerotic appearance to the parts. They are always located away from the sutures and greatly help to determine segmentation.

The derm of the body margin is relatively smooth and undifferentiated in all genera except *Thysanococcus*, in which it is rather sharply defined and may appear to be serrated.

## PORES

Three types of pores only are normally present—an 8-shaped tubular, a trilocular-disk, and a quinquelocular-disk type.

The tubular type possesses the following characteristics: A single external opening followed by a membranous tube, always longer and generally much longer than wide, ending distally in a fairly broad, more or less strongly sclerotic piece, which can be usually, though not always, easily differentiated into two parts, the basal and the distal bars; a centrally located partition which, from a lateral aspect, may or may not be in evidence through a part of the bars or through the bars and partly or almost wholly through the membranous tube connecting them with the external opening, this partition if present, being always delicate through the tube, especially toward the external opening and, owing in part to the single external opening, never producing the effect of splitting the pore entirely into two separate ones; and a typically slender, delicate, and usually much-elongated tube, the bulla, which always issues from the center of the distal bar. When the tubular pore is viewed on end, a figure 8 is seen across the inner surface of its distal bar, even when the partition is not in evidence from a lateral aspect. This 8-shaped effect is apparently produced by the partition, and it would therefore seem that vestiges or rudiments of the partition, as the case may be, are always present. It is discerned only if the pore is not altered in form, such as being in a collapsed condition or pressed out of shape and in position for the inner surface of its distal bar to be adequately viewed, and generally also the pore

[6] As considered in this bulletin, complete segmentation of the thorax requires the definition of its four sections on the ventral surface, and of both sections of the mesothorax and a single section of the metathorax on the dorsal surface; complete segmentation of the abdomen requires the definition of seven of its segments (excluding the first) on the ventral surface, and of eight of its segments on the dorsal surface.

must be sufficiently stained. Under the right conditions its 8-shaped character seems to be always present, though it may be nearly indistinct, more frequently so in small and delicate pores.

Tubular pores are scarce, from 1 to no more than 16 pairs being typically present. They are always scattered and most numerous on or near the body margin. The development of the partitions through them is of diagnostic value, for example, in separating *Phoenicococcus* and *Palmaricoccus* from the other genera.

The two disk types of pores are not fundamentally different in construction from these types occurring in other coccids. They are always associated with the spiracles only, a single pore alone, either with both pairs or with the mesothoracic pair, but not with the metathoracic pair only. Their sizes and shapes vary appreciably, but, along with the number of loculi, are typical for the species. The number of loculi present appears to be of little importance, since both types occur within a single genus as well as in different genera.

## SPIRACLES

Both pairs of spiracles may open approximately on the surface, or the mesothoracic pair alone may open to the surface through an invaginated tube. The character of the latter and the position of its external opening is of generic value; its form, of specific value. The supporting spiracular sclerites, the spiracularіae, may or may not be subequal in size and structure. The structural condition of the spiracularіae may be distinctive for the species, but apparently not for the genus.

A differentiated spot in the body derm near the margin of apparently the posterior section of the metathorax is frequently observable, apparently always present in *Phoenicococcus* and *Palmaricoccus*. It is usually delicate and is termed here simply a "clear area." Its significance is not appreciated, but if the posterior section has not crowded out the first abdominal segment laterad of the leg, then it is in position to be a vestige of a spiracle on this segment.

## BODY SETAE

In distribution the body setae conform to a rather definite pattern. When well represented, they occur in recognized positions throughout, distinguished as rows (the maximum number being five) on the thoracic and all abdominal segments except the posterior abdominal one. With an appreciable number absent the homologies of all may not be confidently determined, but for the most part apparently can be from their positions. With one exception, they conform in size and form within limits depending upon their locations, the exception being a marginal row of comparatively large, rather spinelike setae in one species (fig. 37). Otherwise they are all comparatively small, and some of them may be almost minute, with the following exceptions: The first to fourth pairs on the mesoventral surface of the head cephalad of the head skeleton vary among themselves in size typically for the species, with always 1 or 2 pairs rather long; a single ventromesal pair each on the posterior sections of the mesothorax and the metathorax occur either small or rather long, depending upon the species; and 2 pairs on the posterior abdominal segment always occur as the longest setae of the body. The number and size of the setae are of diagnostic value in segregating some species and genera.

## ANTENNA

The antenna is always either 6-segmented or of the annulated type, but both types do not occur in a single genus. If of the 6-segmented type, the basal segment is either distinctly more than twice as broad, or distinctly less than twice as broad, as any other segment. With a single exception, it is of one or the other size for all species in each genus. The apical segment of the 6-segmented type is always decidedly more elongate than, and may be twice as long as, any other segment, but it is never wider than the widest of the other segments beyond the basal one, and frequently is slenderer through most of its length than any of them. The intervening segments vary in size among the species of all the genera sufficiently to make them of no value in a generic diagnosis, and perhaps of but little value in a specific one.

The setae of the 6-segmented type are of both specific and generic value. Differences in their number on the basal segment can separate *Phoenicococcus* and *Palmaricoccus*, on the one hand, from *Halimococcus* and *Platycoccus*, and in turn can separate the last two genera from each other; whereas the number of setae on the apical segment apparently can separate only *Platycoccus* from the other three genera mentioned. The form and number of setae on the intervening segments, but apparently not of those on the basal and distal segments, can differentiate the species within each genus.

In the annulated type of antenna (fig. 52, *A*, *B*) the basal segments are not equally distinguishable, segments 2 to 4 being clearly defined but never segment 5; the annulations in one species are fewer in number and less strongly marked than in the others; some slight variations occur in number, size, and location of the setae according to the species, and apparently, at least in size and location, according to the individual. The annulated part appears to embrace the apical segment, and may also include some of the next segment.

A small, usually raised and blunt but sometimes spinelike, structure occurs persistently on the distal margin of the second segment in both types of antenna. This may be a modified pore or a sensory structure, but it is here designated simply as a "spinelike process." A pair of small, apparently invaginated structures are always present on the apical segment of the 6-segmented type, or the annulated part of the other type. In the tuberculate type of antenna in other stages apparently this same kind of structure also persistently occurs, characteristically in pairs, frequently appearing as evaginated setae. They are therefore considered in this stage as invaginated setae.

It was not possible to determine the precise positions of the setae of both types of antennae, owing to inability to judge the degree of twisting to which the segments had been subjected. But both types possess two characteristically long apical setae; in the 6-segmented type, one being typically longer and more apical in position than the other.

The presence in this small group of two such strikingly different types of antennae suggests that the phenomenon is of only minor significance.

## ROSTRUM AND ROSTRALIS

The beak, or rostrum, is a subconical organ with a narrow central channel bordered by apparently three more or less connected sclerites. Three pairs of small rostral setae are usually in evidence, 1 pair being

either distinctly basal or apical and the other 2 pairs always apical in position. This distinction in position is of value in separating *Phoenicococcus* from the other genera.

The mandibles and maxillae are closely joined in the caudal portion of the head-skeleton assemblage, producing a tube termed here the "rostralis." The bases of the mandibles and maxillae remain fixed in position, but prior to penetration of the host tissue the greater part of the rostralis is found within a membranous and very elastic pouch, the crumena, which is suspended in the body cavity between the head skeleton and the rostrum. At this time the apical part of the rostralis lies along the central channel of the rostrum, which appears to serve as a guiding and supporting organ for the rostralis.

The rostralis is rather dense, stiff, and smooth in texture, but has a certain degree of flexibility, as demonstrated by its various loops or bends within the body cavity. It is always longer than the body, and may be more than three times as long in young individuals, its length depending to a certain extent upon the species but varying within limits in each. Within the crumena the rostralis has to double back, always producing a characteristic small rounded or ovoid loop, which is usually observed in the cephalic half of the body. An elongate caudal loop is also always formed by the rostralis and, in addition, 1 or 2 loops, varying in form largely according to the species, may be present.

## LEGS

The legs are subequal in size and never decidedly stout, but some variation exists in the shape of the different segments, a character apparently of more specific than generic significance. The trochanter and femur, and also the tibia and tarsus, may be fused, but apparently if the first 2 parts are fused the other 2 always are. The setae on each leg are approximately alike in character, scarce, and may be absent on the femur and tibia. The number of setae on the coxa and their number and the size of one on or near the inner margin of the trochanter are characteristics of generic value. A minute seta, virtually on the thickened basal part of each coxa and trochanter, appears to be always present, though not always readily distinguished.

Bordering the thickened basal part of each trochanter are a few clear spots, probably pores or sensory structures. On the outer margin of each tarsus, nearly always in evidence, is a differentiated spot, sometimes practically flush with the surface and sometimes mildly raised, sufficiently so in 1 or 2 instances to resemble a short stout spine. This may be a pore or a sensory structure, but it is here designated as a "spinelike process." The segments of the legs are frequently twisted out of position and, as with the antennal setae, an accurate representation of their positions in the drawings is not vouched for.

## ANAL SEGMENT

The region caudad of the seventh abdominal segment is apparently composed of a single segment, considered here as the anal segment, although, as will be indicated in the discussion of the last two male stages, it is evidently composed of at least the eighth and ninth abdominal segments. The caudal margin may or may not have 1

or 2 bulges on each side. These are merely slight, rounded, undifferentiated protuberances of the body derm, characteristic of all species of *Phoenicococcus* and *Palmaricoccus*, present in one species of *Halimococcus*, and absent in all other species.

For the most part the setae of the anal segment can be homologized in all species, the anus and the two long caudal pairs of setae being used as orienting points. The anus may be distinct or almost indistinct, and is always on or almost on the caudal margin. If distinct the anus may have a prominent anal ring or none at all. Anal-ring setae may or may not be present, but one or more setae apparently homologous with anal-ring setae are always in evidence. Thus the character of the anus and anal ring is seen to be variable within a small group of insects. Yet these parts may be of generic importance.

#### PUPARIUM

The female is always nonpuparial in this stage. The male is either nonpuparial, partially puparial in the sense that the subsequent instars are entirely covered by the intact dorsal shell with the ventral derm in a more or less ruptured condition, or wholly puparial in the sense that the subsequent instars are enclosed within a shell which is ruptured only caudally, where a characteristic flap, which may or may not remain attached to the shell, is always produced. Within a single genus one species may be wholly puparial and another species not puparial at all. Thus the puparial state is not necessarily of generic, but may be of specific, importance.

### SECOND-STAGE FEMALE

#### WAX

In color, texture, and general quantity the wax is similar to that found in the first stage of the same species.

#### SHAPE AND SIZE OF THE BODY

In outline the body is elongate elliptical, pyriform, or subcircular, with the posterior end more or less constricted and protruding. In cross section the body is rather flat beneath, with varying degrees of convexity above, ranging from a very slight convexity, giving the appearance of a strikingly flat individual, to a pronounced dome-shaped convexity, giving the appearance of a globular individual. From a lateral aspect (fig. 1) in puparial forms the body is predominantly flat beneath with varying degrees of convexity anteriorly and above, within limits both for the individual and the species, but always with the posterior end drawn out into a projection. From a lateral aspect in the single nonpuparial form the body is essentially as in its first stage but with a greater convexity above.

The size of the body varies with the individual and the species, ranging, for fully developed specimens of particular species, typically from about 0.52 mm long and 0.35 mm wide, to 2.2 mm long and 0.80 mm wide. Newly molted specimens may be as small as 0.35 mm long and 0.14 mm wide. The general shape and size of the body are of little generic value except in the genus *Platycoccus*.

## BODY DERM

The term "body derm" is used here to cover the same characteristics as in the first stage. Segmentation ranges from being practically complete, except for that of the prothorax and both sections of the mesothorax on the venter, to being virtually obscure, except for the anal valve and its usual definition in part ventromesally on the abdomen.

The body may be practically membranous throughout in younger individuals, or membranous except for some sclerotization of the posterior end. In fully developed individuals, if nonpuparial, the body remains in a membranous condition; if puparial, it becomes rather strongly sclerotic on the dorsum, and may become only lightly, and never more than moderately, sclerotic on the venter.

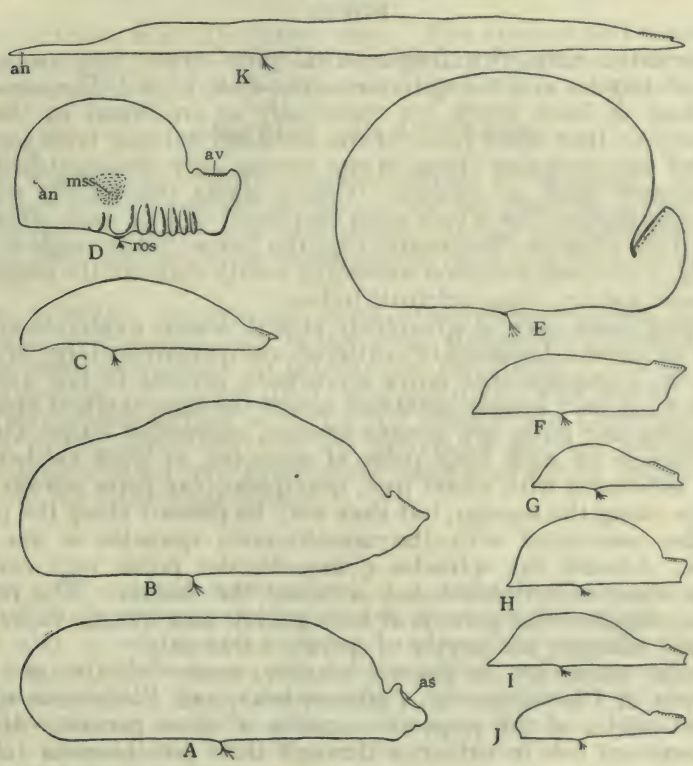


FIGURE 1.—Female puparia of species of the Phoenicococcini, lateral outlines (drawn to same scale): *A, Palmaricoccus attaleae; B, P. pritchardiae; C, P. nesiotes; D, Halimococcus lampas; E, H. thebaicae; F, H. borassi; G, Thysanococcus chinensis; H, T. pandani; I, T. squamulatus; J, T. calami; K, Platycoccus tylocephalus.* × 45.

Papillae are present or absent, numerous or scarce, localized or scattered over one or both surfaces or along the body margin, comparatively prominent or insignificant, and of various shapes, but predominantly spinelike. These papillary characteristics differentiate the species, but are of little generic importance. For instance, within a single genus the papillae may be highly developed or apparently absent. Papillae are most pronounced in young individuals, becoming increasingly obscure as sclerotization develops.

Definite spines are absent except on the dorsum of one species, where they assume a characteristic development. In all but 2 species of 1 genus distinctly reticulated surfaces are absent except on the anal valve, which may or may not possess distinct markings; if so, these markings are usually reticulate. Spicules are frequently plentiful ventromesally on the thorax caudad of the rostrum, and they may be present elsewhere on the ventral surface.

The derm of the body margin is either undifferentiated or the dorsal and ventral surfaces meet along a sharply defined line which may or may not possess a fringe apparently composed of minute specialized spicules or fine granulations. This fringe is of limited generic value, occurring, for example, in all the members of *Thysanococcus* but in no other species.

## PORES

Apparently only two fundamental pore types may occur, the 8-shaped tubular and the quinquelocular-disk type. The structural conditions in both types are essentially as are found in the first stage, except that some pores of the 8-shaped tubular type assume a modified or "variating" form in one species only, distinguished from the ordinary kind as follows: With a single moderately sclerotic bar having flaring sides which seem frequently to fold up or collapse, a moderately sclerotic tube connecting the bar with the single external opening, a delicate partition extending nearly through the connecting tube, and a short, stout sclerotic bulla.

Tubular pores may be apparently absent, scarce, moderate in number, or abundant, localized or scattered, comparatively large or small; if absent, quinquelocular pores are always present in fair numbers, for the most part loosely scattered about the mesothoracic spiracles. Quinquelocular pores are always present, associated either with the mesothoracic or with both pairs of spiracles, or with neither pair. If not associated with either pair, quinquelocular pores always occur in a row along the margin, but they may be present along the margin and also associated with the mesothoracic spiracles in the same species. Around the spiracles quinquelocular pores vary considerably in number, but much less so along the margin. The position of the quinquelocular pores is of both generic and specific value; their sizes and numbers are largely of specific value only.

Tubular pores are in general smaller, more delicate, and more numerous in *Phoenicococcus*, *Palmaricoccus*, and *Platycoccus* than in the first stages of the respective species of these genera. Also the partitions are less in evidence through their membranous tubes in the first two above-mentioned genera. In *Platycoccus* and the other 2 genera the development of the partition assumes similar importance in the 2 stages. Disk pores are normally more numerous, and may be considerably so in all species of the tribe except one, than in their respective first stages.

## SPIRACLES

The mesothoracic spiracles may open approximately on the surface, in shallow depressions, in rather deep roundish pockets, or in elongate granulate invaginations, the last two positions being of distinct generic value. The metathoracic spiracles are found in the first three positions. The spiraculariae are elongate or stout, distinct or indis-

tinct in outline, subequal in size and structure or not, their appearance being of some specific but of little generic value. Clear areas occurring laterad of the metathoracic legs in the first stage are apparently absent in this and all other stages.

### BODY SETAE

The body setae show greater range in number and less range in size than in the first stage, but the homologies of many setae in the two stages are evident. The number and distribution of setae is of generic value in segregating *Phoenicococcus* and *Palmaricoccus*, in which they are most fully represented, from the remaining genera, and in separating the remaining genera from each other.

### ANTENNA

The antenna is always tuberculate. The number and character of its setae are of generic value in segregating *Phoenicococcus* and *Palmaricoccus*, and in turn *Thysanococcus*, from the other genera.

### ROSTRUM AND ROSTRALIS

The rostrum and rostral setae appear to be essentially as in the first stage of the same species, except for the position of the rostrum in relation to the neighboring tissue. In all puparial forms it is invaginated, whereas in the nonpuparial form it is little invaginated, if at all.

The rostralis, as with all other structures, including the head skeleton, is developed anew in this stage, and makes the same sort of movements preparatory to penetrating the tissue of the host as in the first stage. It ranges from being not quite twice as long to more than three times as long as in the first stage of the same species. It varies within limits for both the individual and the species. The development of all structures anew holds true for all stages, except possibly the third-stage female.

### ANAL SEGMENT

The anal segment is composed of apparently the single segment caudad of the seventh abdominal one, as in the first stage. An anal valve may or may not be present; if so, it constitutes the whole anal segment and is always on the dorsal surface, with the anus more or less removed from the caudal margin. If the anal valve is absent, the anus is distinctly on the ventral surface near the caudal margin of the body. The anal valve is always sharply defined and depressed below the surrounding surface.

The details of the parts through which it apparently operates in one species (fig. 13, *B*) may be considered as representative for the tribe. An inner thickening on the surrounding segment serves as a buttress against which the hinge, or cephalic part, of the valve impinges, with the hinge resting upon a ledge or projecting under shelf of the surrounding segment and braced against an inner thickening of the latter. Several teeth of the surrounding segment can be seen forced into the hinge and buttressed by a ridge of the latter to hold the valve firmly in place. The valve can open outwardly only, since a ledge of the surrounding segment extends entirely around the opening. The laterocaudal margin of the valve is somewhat thickened.

The anal valve only rarely has pores, and these are always small and of the tubular type. Several pairs of setae always occur in various positions on the valve. These setae are of specific but of little generic value.

The anal ring may or may not be present in the species possessing the anal valve; if present, it is insignificant, but appears to be of some generic though of no specific value. The anal ring is prominent and anal-ring setae are present in the species having no anal valve, and the anal ring is of distinct value in separating this species from all the others.

#### PUPARIUM

The presence of the anal valve indicates that the instar is puparial. All species are either wholly puparial or not puparial at all in this stage. The nonpuparial condition is of generic importance.

### THIRD-STAGE FEMALE

The structures of the third-stage female are vestigial, and there are apparently none that occur in the preceding instar except the two pairs of spiracles, which are well developed in this stage. The body derm appears to be complete, however, being either delicate or firm, though typically rather brittle, and is usually ruptured to some extent in being removed from the puparium, in which it fits rather tightly. In some species this instar separates from the puparium readily, in others with difficulty. This stage has not been indentified in the monotypic genera *Phoenicococcus* and *Platycoccus*, which are nonpuparial and puparial, respectively, and is apparently lacking in 1 species each from *Palmaricoccus* and *Thysanococcus*, but it is present in all 3 species of *Halimococcus*.

No other intermediate stages were observed in the female.

### ADULT FEMALE

#### WAX

Wax produced in the nonpuparial form is of the same character as that in the first-stage and in the second-stage female. No wax was observed as produced by this stage in the puparial forms, although the number of pores present in each indicates that wax can be produced. The apparent absence of wax in the puparial forms seems to be due to their confinement in puparia.

#### SHAPE AND SIZE OF THE BODY

In the nonpuparial form the body at first is normally moderately elliptical in outline and moderately convex above in cross section, becoming rounder in outline and slightly more convex above in cross section in older individuals. In all other species the body assumes approximately the shape of the puparium containing it, except that the posterior end is less inclined to curve upward as observed from a lateral aspect, and none of its segments is expanded as is sometimes the case to a moderate degree early in the second stage and to a less degree in the later puparium.

In the nonpuparial form the body is appreciably larger than that of the second-stage female; a typical newly molted specimen being

0.52 mm long and 0.35 mm wide, and, when fully developed, 1.3 mm long and 0.98 mm wide. Thus the growth is seen to have more than doubled, and a typical fully developed adult is about double the size of a fully developed second-stage female, which is approximately 0.64 mm long and 0.42 mm wide. In the puparial forms the body is always smaller, but it may be very little smaller or considerably smaller, than the puparium containing it. The measurements for the adults in the smallest and largest puparia, the dimensions of which have already been given, were 0.48 mm long and 0.32 mm wide, and 1.3 mm long and 0.56 mm wide, respectively.

### BODY DERM

The term "body derm" is used here in the same sense as in the first stage and in the second-stage female. Segmentation is always obscure on the dorsum except on the posterior abdominal segments, but is usually in evidence, at least in part, on the venter caudad of the rostrum.

The body is practically membranous at first except frequently for some sclerotization in the anal region, and it remains approximately this way in all puparial forms. In the nonpuparial form there is a great development of papillae, which cover all the ventromarginal and submarginal surfaces, giving the body a rather sclerotic appearance. But there is a definite sclerotization in the narrow sense of the word only when the instar is near maturity, the derm becoming heavy on the dorsal and lateral surfaces but remaining in a membranous condition, at least mesally, on the ventral surface.

In the puparial forms papillae are little more than localized around the spiracles and may be almost, if not entirely, absent here. Definite spines are absent, but spicules may or may not be numerous mesally on the ventral surface. The body margin is not indicated by any dermal markings; nor are there any other noticeable dermal markings than those already mentioned, except for frequent variously appearing striations in the vicinity of the vulva.

### PORES

Two types of pores only are present in the nonpuparial form, the 8-shaped tubular and the quinquelocular disk type. With one exception, only one type of pore, the 8-shaped tubular, is found in the puparial forms. This one exception has quinquelocular pores on the sixth abdominal segment in a location similar to that of the circumgenital pores occurring in typical diaspids. The 8-shaped pores are apparently all of the ordinary kind in both puparial and nonpuparial forms. Thus the variating kind occurring in the second-stage female of one species apparently reverts to type in this stage of this species. The 8-shaped pores are smaller and more delicate than in the second-stage female, and the partition through the tubes may extend hardly more than through the bars in two species of *Palmaricoccus*. But in distribution the 8-shaped pores assume the same general significance as in the previously discussed stages in separating *Phoenicococcus* and *Palmaricoccus* from the other genera. In the remaining genera the 8-shaped pores are characteristically localized laterad of the head skeleton or in the midventral region, although a few may occur on the pygidium.

### SPIRACLES

In all cases the spiracles open practically on the surface. The spiraculariae may or may not be subequal, but they always stand out clearly.

### BODY SETAE

In structure the setae are approximately as in the second-stage female, except for a tendency to a greater specialization on the anal segment of some species. Their general distribution is homologous with that in the second-stage female, but their number is usually greater in varying degrees than in the latter.

### ANTENNA

The antenna may or may not be essentially as in the second-stage female of the same species; the chief differences are the absence of a prominent central sunken area and a membranous base, in its form and size, and in the development of its setae.

### ROSTRUM

The rostrum and rostral setae are essentially as in the second-stage female of the same species. The rostralis ranges from being slightly longer than to about twice as long as in the second-stage female of the same species.

### ANAL SEGMENT

The anal segment embraces all of the apparently single segment caudad of the seventh abdominal one, as in earlier stages, but a sclerotization of its dorsal surface may be extended to include the seventh, and apparently even some of the sixth abdominal segment, giving the anal segment the effect of embracing more segments than it actually does. In the nonpuparial form the anal segment is not sclerotic and is well up on the ventral surface; in all other species it is partly on both surfaces, with the greater part on the dorsum. Its dorsal surface may or may not be partially or wholly sclerotic; when sclerotic it takes on the appearance of a pygidium and is so considered here.

Delicate processes, or squamulae, in general character closely resembling those of typical diaspids, may be present. These squamulae are confined to the laterocaudad margin of the pygidium and frequently appear to possess pores. Tubular pores opening on the surface may or may not be present on the anal segment, but there are always from 4 to 6 pairs of setae here. Some of these setae may be comparatively enlarged. In the puparial forms the anus is always well up on the dorsal surface, most frequently near the center of the anal segment. An anal ring and anal-ring setae may or may not be present.

## SECOND-STAGE MALE

### WAX

Data on wax are available only for *Phoenicococcus marlatti*. It is produced in somewhat larger quantity and laid down in denser fashion than in the female stages of this species, but is essentially of the same general texture and color.

## SHAPE AND SIZE OF THE BODY

The body is predominantly elongate elliptical in outline, with the sides approaching the parallel condition in some cases. In cross section the body ranges from being noticeably flat on both surfaces to being no more than moderately convex above. Instars from round puparia for the most part assume a body outline similar to the latter, and it is natural to suppose that in cross section they should do likewise; but this is not the case, apparently owing to the collapse of the delicate dorsal derm in this stage during preparation of the material.

The size of the body varies appreciably, for both the individual and the species. The newly molted body may be of practically the same size as its first-stage one, or it may be considerably smaller, in both nonpuparial and puparial forms. In the nonpuparial forms some growth takes place; in the puparial forms there is little or no growth, except apparently in length in the instars of two wholly puparial forms, in which the posterior end is observed to project somewhat through the valvular opening of the puparium.

In the nonpuparial forms the range in size of typical newly molted specimens is greatest between species in a single genus, being from 0.29 mm long and 0.17 mm wide to 0.36 mm long and 0.20 mm wide. In the wholly puparial forms it is greatest between typical specimens of species in different genera, being from 0.29 mm long and 0.09 mm wide to 0.40 mm long and 0.18 mm wide. In the partially puparial forms the range is less, being typically from 0.44 mm long and 0.25 mm wide to about 0.47 mm long and 0.22 mm wide. In the nonpuparial forms the increase in growth of the individual is greatest within a single genus, being typically from 0.29 mm long and 0.17 mm wide to 0.46 mm long and 0.21 mm wide. The size of the body may be considered as of little generic importance.

## BODY DERM

The term "body derm" is used here in the same sense as in previously discussed stages. Segmentation ranges from being practically complete, except on the venter cephalad of the mesothoracic spiracles, to being no more than a demarcation of the sclerotic posterior end of some forms.

The body may be practically membranous throughout, or membranous except for some sclerotization of the posterior end. In 2 puparial forms the posterior 3 or 4 abdominal segments are strongly sclerotic, appearing as a single piece which is sharply defined and projects from the puparium. As the instar approaches maturity the sclerotization increases in the nonpuparial forms, but it is not so heavy as frequently on the dorsum of the second-stage female.

Papillae may be absent or scarce, or they may be abundant along the body margin and submargin and around the spiracles. The extremes of papillae being absent or abundant occur within one genus, but the forms involved are puparial and nonpuparial, respectively. The nonpuparial forms always have at least some papillae, which may be scarce and localized. The partially puparial forms are apparently without definite papillae. The wholly puparial forms may or may not possess any; if so, they are always localized and comparatively insignificant. The presence or absence of papillae is of little generic but may be of definite specific value.

Spines are absent, but spicules may be numerous ventromesally on the thorax and abdomen, or in contrast may be practically absent from the body. No reticulated areas or other prominent body markings are present, except that in one species many fine, short, irregular lines are typically intermixed with a row of tubular pores along the ventromarginal and submarginal surfaces. The derm of the body margin is undifferentiated or, if papillae occur in this region, they may be distinguished by their character.

### PORES

Five pore types may occur—an ordinary 8-shaped tubular, an asymmetrical or undivided tubular, a quinquelocular-disk, a trilocular-disk, and a quadrilocular-disk type. The last two types are present only occasionally, a pore of either type in one species replacing a quinquelocular pore normally associated with each metathoracic spiracle. The 8-shaped tubular and the quinquelocular and trilocular disk types are of the same general character, exclusive of certain variations in size and shape, as corresponding types occurring in the first stage. The quadrilocular-disk type differs in essentials from the other disk types only in the number of its loculi. The asymmetrical tubular type is characterized by having apparently a single sclerotic bar with no more than a mild central depression, a distinct bulla issuing from the inner lateral margin of the bar, and a single membranous tube connecting the bar with the external opening.

All pores, or the disk type only, may be absent from the body, or either tubular type may be scarce or abundant. Both tubular types, or either type alone, may occur in the same species. Tubular pores may be less or considerably more abundant than in the second-stage female of the same species or even in all species of the same genus. In *Phoenicococcus* and *Palmaricoccus* the distribution and structural conditions (excluding size) of the tubular pores are essentially of the same character as in the second-stage female of the same species. Thus, these genera can also be segregated from the other genera in this stage, as in the previously discussed stages, by the character of their tubular pores. When present the disk type of pore is always associated with either pair, or with both pairs, of spiracles, and pores of this type are no more numerous, or, much more frequently, distinctly less numerous than the spiracular pores in the second-stage female of the same species.

### SPIRACLES

Both pairs of spiracles always open approximately on the surface. The spiraculariae are usually subequal and elongate, and may or may not be strongly sclerotic.

### BODY SETAE

The comparison presented between the body setae of the first stage and those of the second-stage female can be similarly applied between the first stage and this stage. The body setae may be less numerous, more numerous, or in about the same numbers in both sexes of the second stage of the same species, even in the same genus (*Palmaricoccus*).

### ANTENNA

The antenna is always tuberculate. It is segmented and prominent in the nonpuparial forms, but is hardly more than a slightly thickened spot in all except one of the wholly puparial forms. In this one exception it may or may not be a mere thickened spot, but it is never more than a simple rounded tubercle. In the partially puparial forms the contrast between the development of the antenna in the two sexes of this stage is slight or insignificant. The puparial condition seems to exert a definite influence on the development of the antenna.

### ROSTRUM AND ROSTRALIS

The rostrum and rostral setae are similar to these parts in the first stage and the second-stage female of the same species. The rostralis is always longer than the body, but may be very little longer or more than five times as long; the closest agreement and the greatest disparity between the length of the rostralis and that of the body occur in two wholly puparial forms but in different genera. The rostralis is always shorter than in the second-stage female of the same species, ranging from less than one fourth to more than one half as long. It may be moderately shorter than, but not one half as short or more than twice as long as, that of the first stage of the same species. When a corresponding comparison is made of the length of the rostralis in the second-stage male, the second-stage female, and the adult female of each species, a general tendency is revealed for the rostralis to vary in length proportionately among these stages; but the rostralis of the first stage fits in less satisfactorily with this proportionate variation in length. The length of the rostralis for any stage appears to be of little generic, but may be of definite specific, value.

### LEGS

Vestigial legs may be obscure or distinct, even to showing evidences of segmentation and in the possession of setae. All three pairs of legs are not always equally developed.

### ANAL SEGMENT

The anal segment embraces apparently the single segment caudad of the seventh abdominal segment, as in previously discussed stages. In *Phoenicococcus* there is a close resemblance between the general character of the anal segment in this stage and that in the second-stage female. In all the other species there is a closer similarity between the anal segment in this stage and that of *Phoenicococcus* in this stage than there is between the anal segment of any of them in this stage and that of their respective second-stage females, owing to the presence of an anal valve in all the second-stage females. The presence or absence of an anal ring and anal-ring setae agrees with the situation in the first stage of the same species.

## THIRD-STAGE MALE

There is no reason to believe that the third-stage male is ever absent, although specimens of some species were missing in the writer's material. All specimens available indicate that the body is

moderately elliptical in outline and, in general, with evenly rounded anterior and posterior ends. In cross section it is moderately convex above. The body is slightly smaller than that of the fully developed second-stage male of the same species. The distribution of body setae is apparently homologous with that in the previously discussed stages.

The anal segment embraces the entire apparently single segment caudad of the seventh abdominal one, as it does in the previously discussed stages. On the meson of the ventral surface of the anal segment is a sclerotic area with an inwardly projecting piece (fig. 7), which apparently, from the way the caudal segment of the developing subsequent instar is folded around it, is the connection in this region between this instar and the subsequent instar. The increased body length of the fourth instar makes something like this necessary. For a similar reason the two basal segments of each appendage of the fourth instar are developed more or less outside these parts of the third instar, in a telescoped fashion. Other structural matters dealing with the third-stage male are discussed in the section on classification.

## FOURTH-STAGE MALE

The body differs in shape from that of the preceding instar in being slightly longer and narrower in outline, possibly somewhat flatter above in cross section, and in having a characteristic caudal projection. In segmentation, sclerotization, and number and distribution of setae the body proper is essentially as in the preceding stage of the same species, except that the caudal projection is clearly defined as a separate segment, with an intervening segment between it and the seventh abdominal one. The caudal projection then apparently constitutes the ninth abdominal one and bears the anus. If this is so, the anal segment in previous stages is actually composed of at least the eighth and ninth abdominal segments. The determination of the particular segment to which the setae of the composite anal segment belong is believed possible from their location in relation to each other and to the anus, and from the usually larger size of one in a pair on each side along the ventrocaudal margin of all the male stages up to and including this stage.

The increased length of the body and its appendages in the adult male makes it necessary for some parts to develop apparently outside the corresponding parts in the fourth instar. This crowding out is most noticeable at the posterior end where the long caudal projection of the adult male extends to the sixth abdominal segment, or beyond, in the fourth instar (figs. 8 and 16), pulling with it the eighth abdominal segment of the adult, which is folded back over the segment or segments immediately cephalad of the latter. The base of the caudal projection of the adult may also be bent over. For a further discussion of the structural parts of the fourth-stage male the reader is referred to the section on classification.

## ADULT MALE

### SHAPE AND SIZE OF THE BODY

The shape of the body is predominantly elongate elliptical. In some forms the sides approach the parallel condition; in others a mild bulging of the thoracic segments in particular is noticeable along

the margin. The posterior end is always drawn out into a smooth rapierlike projection.

There is a considerable variation in the size of the body, the range in the available material, both for the individual and for the species, being approximately from 0.37 mm long and 0.12 mm wide, to 0.59 mm long and 0.19 mm wide, measuring in all cases to the tip of the posterior projection.

### BODY DERM

The term "body derm" is given the same significance here as previously. Segmentation ranges from being complete to more or less obscure over the greater part of the ventral surface; also the anterior section of the mesothorax on the dorsum may not be defined. The body is membranous except for some sclerotization of the posterior end. Papillae and spines are absent, spicules insignificant or practically absent. The body margin lacks configurations and is not well defined.

### WINGS AND THORACIC WING FRAMEWORK

This group of insects is characteristically without well-developed wings and the thoracic wing framework is practically absent. There is no sign of even vestigial wings except in one species.

### SPIRACLES

The spiracles open approximately on the surface. The spiraculariae are prominent and inclined to be stout and appreciably sclerotic.

### BODY SETAE

In number and distribution the setae are essentially as in the two preceding instars of the same species, but in size they are longer in general and some of them appreciably larger and longer on the head and posterior end than the corresponding ones in the two preceding instars.

### ANTENNA

The antenna occurs characteristically with two stout basal segments and a distal club. The club varies considerably in form and in the number of its segments for each species, ranging from being noticeably stout to rather slender, and having from 3 to 8 segments. The setae on the club vary greatly in form, size, and number among the various species, but are relatively stable in these characteristics for the individuals.

The character of the antenna may be of some generic value, but more frequently it is of specific value.

### EYES

Either one or two pairs of simple eyes are present, the extra pair always being somewhat smaller and situated on the ventral surface well removed from the other pair, which is on or near the body margin. The number of pairs of eyes is not distinctive for any one genus.

### HEAD SKELETON AND ROSTRUM

Only possibily the merest vestiges of the head skeleton and none of the rostrum are ever present except in one species, where both of these structures can be recognized but are in a decidedly vestigial condition. It is in this species that vestigial wings occur.

### LEGS

The legs are well developed and in general of stouter proportions than in the first stage; also the metathoracic pair are typically stouter than the others. The number and character of the leg setae vary greatly and may be of both specific and generic value. Pronounced sensory areas on the legs are present in *Phoenicococcus* and are of value in separating this genus from all the others.

### ANAL SEGMENT

The anal segment embraces the ninth, but not the eighth, abdominal segment, as in the preceding stage. The posterior projection is a sheath having a deep central, but open, channel for holding, guiding, and generally supporting the penis. It is termed here the "genital sheath," and appears to be of but little generic or specific importance. The anus varies in prominence and location, but these features seem to be of no generic and of little specific value. The number of setae on the anal segment is not distinctive for any one genus, but seems to be of use in separating *Halimococcus* and *Platycoccus* from the other genera.

## CLASSIFICATION

The Phoenicococcini possess the characteristics listed below which can distinguish the group, in that one or more of these characteristics do not hold for some corresponding stage or stages in any other coccid species.

*Absent in all stages.*—Characteristic secretionary formations or resinous secretions, gall formations, cerarii, dorsal ostioles, ventral cicatrices, brachial plates, dorsal spines, cribriform plates, more or less sessile unilocular pores, bilocular-disk pores, multilocular pores with more than five openings, clearly distinguished partitions entirely through tubes of tubular pores including external openings (the latter appearing 8-shaped) or a separation of tubes of tubular pores into two parts, sclerotic areas near inner end of a tubular pore separated by a membranous area, inner ends of any pores with a characteristic and apparently normal twisted 8-shaped effect, 8-shaped pores noninvaginated or so slightly as to be as broad as the invaginations are deep, anal-ring pores, any other than tubular pores on the two posterior abdominal segments, abdominal spiracles, distinct setaceous areas, generally distributed spiniferous areas (a spiny area present, localized on dorsal surface of second-stage female in one species), a segmented beak or rostrum, an invaginated anus, anal cleft, anal plates, anal lobes, anal tubercles (undifferentiated caudal bulges of body derm present in first stage of some species), pygidial lobes, abdomen with clearly emarginated caudal end.

*Absent in all stages except adult female.*—Pygidium, pygidial plates or squamulae, pores on anal segment appreciably projecting beyond body margin (last two characteristics present in adult female of one species only).

*Absent in all stages except second-stage male.*—Any other than these three pore types—a tubular type with 8-shaped effect at inner end of pore, a trilocular type, and a quinquelocular type.

*Absent in adult male.*—Any other than a single smooth rapierlike posterior projection, thoracic wing framework and well-developed wings, compound eyes or more than two pairs of simple eyes, ocelli.

In first stage setal shafts not forked or with serrated margins or lateral projections, with two pairs of characteristically long, closely associated caudal setae, much longer than any other body setae and with inner pair considerably the longer, but only moderately larger at base than the outer pair, antenna with six segments only, or of the annulated type possessing either 13 or 14 setae, anus distinctly on ventral surface or on, or practically on, caudal margin. In second and adult female stages eyes and legs absent, antenna tuberculate, possessing no more than a 1-segmented sclerotic piece and an insignificant membranous base, rostrum well developed. In adult female having anus on dorsal surface, with no more than six pairs of tubular pores altogether on the three posterior abdominal segments, or on pygidium if present. In second-stage male eyes apparently absent, antenna no more than tuberculate, legs quite vestigial or absent.

This rather long list of items gives in detail the limitations of the tribe, but its members can be segregated from all other coccids by the following characteristics: Absent in all stages, abdominal spiracles, cerarii, dorsal ostioles, more or less sessile 8-shaped pores, tubular pores with their external openings double or 8-shaped, multilocular pores with more than five openings, anal-ring pores, anal cleft, anal plates, anal lobes, pygidial lobes; the absence of a pygidium in all stages except the adult female; absent in adult male, compound eyes, thoracic wing framework; except in second-stage male, the presence of the asymmetrical type of tubular pore; present in first stage, anus on ventral surface or on, or practically on, caudal margin of body only, two closely associated pairs, no more and no less, of comparatively long caudal setae, the inner pair always being distinctly longer than the outer pair.

The grouping of the members of the Phoenicococcini as given here is only a tentative arrangement. For practical purposes they can be separated satisfactorily into several genera, but when data on additional material are available this classification may not hold. Also the writer lacks an adequate understanding of the significance to be attached to practically all the characteristics exhibited by these insects, and hence those used in segregating the respective stages of the various species. After all, there are only 12 species involved, peculiar in that they evidently do not fall within any established group or have any definitely recognized affinities. Until an adequate study of sufficient material in the group has been made, and probably also until more is known concerning the true significance of comparable structural features in other coccids, no sound classification of them is possible, nor is a statement justified as to the phylogenetic ranking of the genera or the species within the genera.

The 12 species placed in the tribe Phoenicococcini are segregated into 5 genera, 3 of which are newly established here. The more important reasons for this segregation follow.

*Phoenicococcus* Cockerell, as typified by its single species, can be distinguished from all other species in the tribe in that the second-stage female lacks an anal valve and the position of the anus in relation to other parts of the body in this stage and in the adult female is strikingly different from that in the corresponding stages of the other species.

The three species assigned to *Palmaricoccus*, new genus, can be distinguished from the remaining eight species in that all 8-shaped tubular pores have partitions almost through their membranous tubes; the egg has only a single spine; the first stage has a larger number of setae on the abdomen, the first two antennal segments, and each trochanter, and has a prominent anal ring; the second-stage female

has more setae on the head, abdomen, and antenna; the adult female has the 8-shaped tubular pores scattered over at least the ventral surface of the body, and the antenna also has a larger number of setae.

*Platycoccus*, new genus, as typified by its single species, can be distinguished from all other species of the tribe in that the egg has two disconnected spines, the second-stage female has the head prolonged as a distinct projection, the puparium is markedly flat, and the tubular pores are comparatively numerous along the body margin, particularly laterad of the head skeleton.

The three species assigned to *Halimococcus* Cockerell can be distinguished from the four remaining species of the tribe in that the first stage has the external openings of the tubular pores approximately flush with the surface, the mesothoracic spiracles are within small invaginations which open to the surface away from the body margin, and it has the 6-segmented type of antenna; the second-stage female lacks a fringe around the body margin, has few tubular pores, not enough to form a long row, has five or more times the number of quinquelocular pores associated with the mesothoracic spiracles, which open into roundish pockets, and the antenna has two minute setae only.

The four species assigned to *Thysanococcus*, new genus, can be distinguished from all other species in the tribe in that the first stage has the external openings of the tubular pores on small sclerotic projections, the mesothoracic spiracles within prominent granulate invaginations which open to the exterior approximately on the body margin, and the annulated type of antenna; the second-stage female has the body margin more or less fringed, the mesothoracic spiracles within elongate granulate invaginations, and the antenna always with one or two rather prominent fleshy setae, but no more.

Of the 11 species included here as relatives of the date palm scale (*Phoenicococcus marlatti*), 4 have been previously described and 7 are recorded as new. As far as is known, no synonyms have occurred in the literature for any of the previously described species except *P. marlatti*, which has appeared under the names *Sphaerococcus draperi* (*4, p. 12; 14, p. 70*) and *S. marlatti* (*3, p. 11; 7, pp. 14–15; 8, p. 37; 9, p. 34; 11, p. 248; 14, p. 104; 16, p. 221*). Morrison (*13, p. 671*) has stated that this species "has no close relationship whatever with *Sphaerococcus*", and after an examination of some *Sphaerococcus* material, the writer also vouches for the fact that *P. marlatti* does not belong there.

## Subfamily PHOENICOCOCCINAE, new subfamily

This subfamily is created for the reception of the single tribe Phoenicococcini, new tribe, which in turn is created for the reception of the five genera with which this bulletin is particularly concerned. The characterization of the tribe as given below will, for the present, serve for the subfamily as well.

### Tribe PHOENICOCOCCINI, new tribe

#### TRIBAL CHARACTERISTICS

##### Egg

Derm membranous, very delicate; no recognizable structures present except 1 or 2 single spines or a single group of 3 to 12 spines, all mesally situated on or near the cephalic margin; all spines distinctly sclerotic; the single spines rela-

tively broad and short, almost tuberculate in form but always acutely pointed; spines in the group more characteristically spinelike in form, comparatively stout, and varying in size, position, and degree of crowding in each group, not only for the species, but mostly in a lesser degree for the individual as well; body derm around bases of single spines not sclerotic, but that around the bases of groups moderately sclerotic, and the sclerotization somewhat changeable in outline.

### First Stage

Wax frequently little or not at all in evidence, or may entirely cover body, especially in nonpuparial forms; filamentous or matted in appearance and whitish in color. Body elongate ellipitical, with or without bulges along caudal margin; in cross section younger specimens more or less flat, but in older ones may or may not be distinctly roundish; its segmentation may be nearly complete or only partially indicated, if the latter, mostly so on abdominal segments; may be membranous throughout or posterior abdominal segments, especially the caudal or penultimate segment or both, may be sclerotic, and there may also be some sclerotization around head skeleton and rostrum; may or may not be firm in contour and margins more or less serrate in appearance. Only three types of pores normally present, an ordinary 8-shaped tubular, a trilocular-disk, and a quinquelocular-disk type; 8-shaped tubular type and either the trilocular or quinquelocular disk types always present, but not all three types in same species. Tubular pores situated on body marginally, submarginally, or dorsomesally, never decidedly ventromesally, much more often occurring on or near margin, with no more than 2 pairs to 1 segment, and ranging in number from 1 to about 16 pairs; may be small or large, slender or stout, delicate or pronounced in appearance, and vary distinctly in size for any one species; in such a case smaller pores more frequently submarginal or mesal in position, larger ones more marginally situated. For any one species all trilocular or quinquelocular pores closely associated with mesothoracic spiracles alone or with both pairs of spiracles, but not with metathoracic spiracles alone; no more than 1 such pore associated with any one spiracle; may or may not be comparatively large, may or may not have indented margins, may or may not be invaginated. The mesothoracic, but not the metathoracic, spiracles may or may not be invaginated; spiraculariae elongate or stout, strongly sclerotic or only moderately so, subequal or not. A clear area laterad of each metathoracic coxa may or may not be in evidence. The majority of body setae usually short, insignificant in appearance, and distributed in general over all segments, mostly in recognized positions with the larger number in rows on or near the body margin; from 1 to 4 pairs on ventral surface of head always larger and longer than the other head setae, 1 ventromesal pair each on mesothorax and metathorax may or may not be comparatively prominent, a row entirely around body margin noticeably long and spinelike may be present, 2 pairs on or near caudoventral margin of anal segment, much longer and usually much larger than any other body setae, always present, with the more mesal pair almost or quite half the length of body or more, and the outer pair from about one fifth to three fourths the length of the mesal pair; typically from 9 to 12 pairs on head, 3 to 4 pairs on prothorax, 4 to 7 pairs on mesothorax, 3 to 8 pairs on metathorax, none to 5 pairs each on first to seventh abdominal segments, inclusive, and 5 to 7 pairs on posterior abdominal segment; in all, 33 to 69 pairs present. Antenna either of the 6-segmented or of the annulated type; if the former, the basal segment may or may not be twice as broad as any other, and distal segment considerably longer and may be more than twice the length of any other segment; basal segment of 6-segmented type, with from 2 to 4 slender setae, second segment, none, 1, or 2 slender setae; third, none to 4, 1 of which may be fleshy; fourth, none or 1 fleshy seta; fifth, 2 or 3 slender setae and 1 fleshy seta; and sixth segment, 2 to 4 slender setae, 2 of which are always apical in position and noticeably long, and 5 fleshy setae; if of the annulated type, from 2 to 4 basal segments more or less delimited, and with either 13 or 14 setae scattered over the antenna; distal margin of second segment of both types with a more or less spinelike process, or possibly a pore, almost always in evidence, and sixth segment, or annulated part, as the case may be, always with a pair of minute structures, apparently invaginated setae. If this stage is nonpuparial, rostrum not invaginated; if wholly puparial, rostrum appreciably invaginated, producing an apparent opening quite noticeable when rostrum is withdrawn during molting; rostrum with apparently none or 1 to 3 distinct pairs of setae, 2 of which are always distad in position; rostralis always with 1 characteristic small cephalic loop and 1 to 3 other loops of various sizes, shapes, and positions, when uncoiled within body. Legs may be slender or rather stout; trochanter and femur, also tibia and tarsus,

may be fused; fleshy leg setae absent; typically from 3 to 6 and either 2 or 3 setae on coxa and trochanter, respectively, 1 seta on each of these segments being always minute and situated near basal articulation of segment, none to 3 setae on femur, none or 1 on tibia, if present always on inner margin, 3 on tarsus, 1 being on inner margin and the other 2 on outer distal margin, besides a more or less spinelike process nearly always in evidence on outer margin of tarsus, and 1 pair of setae on inner margin of basal part of claw. Anus always approximately on caudal margin; anal ring and anal-ring setae may or may not be present. Male instar nonpuparial, partially puparial, or wholly puparial.

### Second-Stage Female

Characteristics of wax essentially as in first stage of same species. Body outline either moderately or elongate elliptical, pyriform, or subcircular with posterior end constricted; in cross section younger specimens moderately convex above or markedly flat; if nonpuparial, changes comparatively little in shape; if puparial, becomes much more convex above and may become almost globular in appearance over its greater part or may remain decidedly flat; general outline continued evenly around both ends, or either anterior or posterior end projecting, but without bulges along caudal margin; its segmentation may range from being nearly complete for all segments to being practically obscure throughout, except for anal segment; younger specimens membranous throughout or posterior end may be moderately or strongly sclerotic; if nonpuparial, it remains membranous throughout; if puparial, it becomes sclerotic on dorsum but remains membranous, or at least no more than moderately sclerotic, on venter; body margin rounded and well defined or not, or may appear as a sharply delimited line either simple in character or fringed with what appear to be fine spicules or granulations; papillae present or absent, if present, may be insignificant or prominent in appearance, scarce or abundant, localized or generally distributed, typically more numerous marginally and submarginally. Only two fundamental pore types present, the 8-shaped tubular, either ordinary or variating in structure, and the quinquelocular-disk type; both types present, or apparently the quinquelocular type alone, in a single instar. Tubular pores may be of the ordinary kind only, as in the first stage, or both the variating kind and the ordinary kind may be present; tubular pores may be scarce, moderate in number, or abundant, ranging in number from 1 or 2 to about 800. Quinquelocular pores may be associated with both pairs of spiracles or with mesothoracic, but not with metathoracic spiracles alone; they may or may not be invaginated, if so, apparently always open on body surface; when present, from 1 or 2 to nearly 60 associated with each of 4 spiracles. Quinquelocular pores may occur singly or in about 6 to 17 groups, each with from 1 to 5 pores, in a marginal or submarginal row extending almost around body margin; noninvaginated; when present, typically from 19 to 31 pores on each side. Both pairs of spiracles may be situated on surface or in shallow depressions or deep pockets, or the mesothoracic, but not the metathoracic, pair alone may be in shallow depressions or in distinct pockets or in elongate invaginations from body margins; when in deep pockets, accompanied by quinquelocular pores of at least two distinct sizes, the larger ones opening on surface, the smaller ones situated well within the pockets; spiracularіae elongate or stout, prominent or obscure, subequal or not. The distribution of body setae is of the same general character as, but they vary much less in size and considerably more in number than, in first stage, ranging in number typically as follows: Head, none to 14 pairs; prothorax, none to 7 pairs; mesothorax, 1 to 10 pairs; metathorax, 2 to 9 pairs; first abdominal segment, none to 3 pairs; second to seventh abdominal segments, inclusive, none to 7 pairs each; anal segment, 3 to 7 pairs; in all, 8 to 77 pairs present. Antenna with or without membranous base; sclerotic part may be rounded or irregularly fashioned, and may or may not have a central sunken area; always with at least two small invaginated setae, and may possess from none to as many as five fleshy setae of varying lengths. If this instar is nonpuparial, rostrum not invaginated; if puparial, rostrum appreciably invaginated, producing an apparent opening into body cavity that becomes a distinct slit when, on molting, rostrum is withdrawn entirely within body; rostral setae of same general character as in first stage of same species; rostralis always with a characteristic small cephalic loop and three additional loops of varying forms, when uncoiled within body; if body derm is membranous on venter, rostralis of adult is forced through undifferentiated tissue in varying locations near caudal end of rostral slit; if body derm is sclerotic on venter, rostralis of adult is forced through either one of a pair of membranous areas on each side of rostral slit, or

through a single mesal membranous area caudad of rostrum. Anal valve present or absent; if absent, this instar not puparial and anus distinctly on ventral surface; if present, this instar puparial and anus well up on dorsal surface; sharply defined and sunken below the surrounding laterocaudal surface; except basally, its covering tissue frequently appears reticulated or imbricated; only rarely with pores, these tubular, with no more than two pairs present, minute or almost obscure and situated along caudal margin; anus may be fairly large or minute; anal ring and anal-ring setae may or may not be present.

### Third-Stage Female

Not observed in nonpuparial form. May or may not be present in puparial forms; if so, body with comparatively few recognizable structures. When present, body fits snugly within puparium. Body derm may be delicate or firm and distinct; without recognizable papillae, pores, setae, antennae, head skeleton, rostrum, or any other structures occurring in preceding stages, except the two pairs of spiracles which apparently are always well developed. Many thin roundish spots may be present in body derm, evidently to accommodate tubular pores of preceding instar; each either empty or with a pore, in material removed from a puparium. Sclerotic tubercles may be present on body derm, varying in number and size for both individual and species. On development of adult, head skeleton and rostrum of puparium simply drop down or swing around into an inverted position.

### Adult Female

When observed, texture, color, and quantity of waxy matter essentially as in second-stage female of same species. Body either moderately or elongate elliptical or pyriform, with anterior or posterior end either projecting or not, but with no distinct bulges along caudal margin; shape of nonpuparial form at first similar to that of second-stage female, but in older specimens rounder in outline and more convex above in cross section; shape of partially and wholly puparial forms, in both younger and older specimens, similar to that of second-stage female of same species; segmentation obscure, except occasionally on ventral surface of thorax caudad of rostrum and of abdomen and on dorsum of posterior end of partially and wholly puparial forms; young individuals may be lightly sclerotic throughout and older ones heavily sclerotic on dorsum, or both young and old individuals may be practically membranous throughout, or membranous except for sclerotization of posterior end; body margin rounded and indistinctly defined, never with a fringe; papillae present or absent, if species nonpuparial in female, more or less densely covering marginal regions and prominent, if puparial, scarce and localized and not so prominent. Only two pore types present, the ordinary 8-shaped tubular and the quinquelocular-disk type; both types may be present, or only the tubular one, but not the quinquelocular type alone; tubular pores scarce, moderate in number or numerous, scattered over venter or over both surfaces or localized on venter largely along margin and submargin, or largely in a pair of indistinctly defined clusters situated mesally on thorax only or on both thorax and abdomen; anal segment may or may not possess up to about six small pairs; in all, typically from 8 to 360 tubular pores present; if species is nonpuparial in female, quinquelocular pores always associated with both mesothoracic and metathoracic spiracles, typically to the number of 6 to 30 and 1 to 15, respectively, with each pair, and present nowhere else; if puparial in female, no quinquelocular pores associated with either pair of spiracles, but rarely in an irregular band having typically from 20 to 26 pores, on sixth abdominal segment. Both pairs of spiracles open approximately on surface; spiraculariae elongate or stout, clearly sclerotic, and may or may not be subequal. Distribution and size of body setae of same general character and usually as numerous as, and may be distinctly more so than, in second-stage female; typically from none to 20 pairs on head, 4 to 40 pairs on thorax, and 11 to 50 pairs on abdomen; in all, 17 to 110 pairs present. Antenna with or without a prominent central sunken area and membranous base; with from 1 to 5 fleshy setae and a small pair of partially or wholly invaginated setae, or with a pair of partially invaginated setae only. Rostrum, rostral setae, and rostralis of same general character (not considering size) as in second-stage female of same species. A pygidium may or may not be present; if absent, anus may be distinctly on dorsal or distinctly on ventral surface; pygidial area apparently may be restricted to anal segment or extend cephalad onto seventh, and even sixth, abdominal segment; anal segment with from 2 to 6 pairs of tubular pores, always located along caudal margin, and with from 2 to 6 pairs of setae of varying sizes and positions; pygidial plates or squamulae, in the sense of delicate processes

projecting from the caudal margin, rarely present; no such plates or squamulae anywhere else on body; anus may be minute or comparatively large; anal ring and anal-ring setae may or may not be in evidence.

### Second-Stage Male

Waxy secretions, when observed, of same general texture as in other stages, but inclined to be denser and cover body better. Body moderately or elongate elliptical, with anterior and posterior ends more or less evenly rounded; segmentation may be nearly complete or obscure except partially on venter of thorax and abdomen; very lightly sclerotic in general, or membranous except for sclerotization on posterior abdominal segments; margin indistinctly or clearly defined, but never fringed; papillae present or absent, if present, scarce or fairly abundant but localized along margin and submargin or on posterior end. Three pore types normally present, the ordinary 8-shaped tubular, an asymmetrical tubular, and the quinquelocular-disk type, which in one species may occasionally be replaced by either the trilocular or the quadrilocular disk type; if preceding instar is wholly puparial, all types of pores apparently may or may not be absent, if nonpuparial or partially puparial, all pores never absent; apparently the 8-shaped tubular type only, both tubular types only, or the 8-shaped tubular and a disk type, or the asymmetrical tubular and a disk type, but not a disk type only, may be present in any one species; 8-shaped tubular pores delicate or pronounced in appearance, scarce or numerous, localized or scattered over both surfaces, and, when present, ranging in number from 6 to 350; asymmetrical tubular pores moderately prominent and localized in distribution, typically 1 to 2 and 2 to 6 occurring on anterior and posterior ends, respectively, or in a ventromarginal and submarginal row containing about 50 well-distributed but irregularly placed pores extending almost entirely around body; when present, typically from 1 to 8 disk pores associated with each mesothoracic and from 1 to 3 with each metathoracic spiracle, or a single pore with each one of either pair of spiracles alone. Spiracles open approximately on surface; spiraculariae elongate, and may be decidedly so, lightly or strongly sclerotic, subequal. Distribution, size, and number of body setae may or may not be approximately as in second-stage female of same species; their range in number of pairs typically as follows: Head, 5 to 15; thorax, 4 to 25; abdomen, 8 to 43; in all, 23 to 80 pairs present. Antenna may be more vestigial, less vestigial, or essentially as in second-stage female of same species. Rostrum and rostral setae apparently similar to these parts in second-stage female of same species, but rostralis may be reduced to one shallow loop besides the characteristic small cephalic one. Legs vestigial, but showing a varying degree of development; may be entirely obscure or, in contrast, may show evidences of segmentation and possess minute setae. Anus on or near caudal margin; prominent or minute; with or without anal ring and anal-ring setae.

### Third-Stage Male

Body moderately elliptical in outline, with the anterior and posterior ends evenly rounded in general; in cross section moderately convex above; segmentation may be almost complete and distinct; membranous throughout; papillae and pores absent. Vestigial wings may or may not be present; if so, the two subsequent instars also with vestigial wings; if absent, the two subsequent instars without any evidence of wings. Spiracles open approximately on surface; spiraculariae may not be sharply defined or only very moderately sclerotic, apparently subequal. Body setae essentially of same character, but may be less or greater in number than in preceding stage of same species, but at least always with several pairs on posterior abdominal segment; their distribution of the same general character as in first stage and female stages; mostly small, delicate, and with unusually short shafts, but frequently with a prominent pair on caudal margin of posterior abdominal segment. Antenna and legs externally developed; without recognizable pores or setae; more or less distinctly segmented, indicated by indentations and sclerotic areas; typically short, stout, and tapering toward their apices. Outlines of head skeleton and rostrum complete and distinct, but the parts in a vestigial condition. Eyes and rostralis absent. Anus on or near caudodorsal margin; distinct. Connection with developing ninth abdominal segment of subsequent instar usually distinctly in evidence on or near caudoventral margin of posterior abdominal segment.

### Fourth-Stage Male

Body moderately or elongate elliptical; anterior end evenly rounded in general but posterior end always with a short stout projection, the ninth abdominal segment; segmentation and sclerotization essentially as in preceding stage; papillae and pores absent. Spiracles, spiracullariae, and body setae similar to these parts in preceding stage of same species, except spiracullariae usually slightly better defined and more sclerotic. Antenna and legs more developed than in preceding stage, more elongate, and their segmentation and sclerotization more pronounced; without recognizable pores or setae; legs may or may not be sharply elbowed. Outlines of head skeleton and rostrum may or may not be complete; in all cases observed in a more vestigial condition than in preceding stage of same species; invagination to alimentary tube apparently always present. Eyes and rostralis absent. Anus always well up on dorsal surface, usually distinct. Connection with developing ninth abdominal segment of subsequent instar generally obscure.

### Adult Male

Body elongate elliptical in outline, with posterior end always projecting as a smooth, more or less sclerotic, rapierlike structure; in cross section flatter than fourth-stage male; segmentation may be complete or only partially so; membranous in general; may or may not appear delicate. Thoracic wing framework absent, or, at most, possibly indicated in one species by a depression along cephalic and caudal borders of mesothorax; wings absent, or in one species in a vestigial condition. Spiracles open approximately on surface; spiracullariae elongate or stout, mostly strongly sclerotic, and subequal. In distribution and size body setae essentially of same general character as in first stage of same species; in the available complete records varying in number as follows: Head, 9 to 11 pairs; prothorax, 4 to 6 pairs; mesothorax, 2 to 8 pairs; metathorax, 2 to 6 pairs; first to eighth abdominal segments, inclusive, none to 5 pairs each; ninth abdominal segment, either 3 or 4 pairs; in all, 31 to 66 pairs present. Antenna with 2 stout basal segments and a distal club composed of from 3 to 8 segments; club may be stout or elongate; basal segment with 2 or 3 slender setae; second segment with 3 to 5 slender setae; club segments with a varying number of slender, fleshy, or spinelike setae, in all ranging from about 14 to 60 in number; a pair of very small invaginated setae apparently may or may not be present on distal segment of club. Either 1 or 2 pairs of eyes present, 1 pair slightly smaller than the other and distinctly on ventral surface. Head skeleton absent except for possibly an extreme vestige or so, and rostrum absent, or head skeleton and rostrum may both be present though with parts very vestigial; rostralis absent; an invagination to alimentary tube present, but may be too delicate to discern easily. Legs inclined to be stout; mesothoracic pair, especially tibia and tarsus, frequently stouter than these parts of the other legs; setae comparatively scarce or abundant, usually more numerous on the metathoracic legs; setae slender, fleshy, or spinelike; all three pairs with a minute seta each near basal articulations of coxae and trochanters, and apparently may or may not possess a small spinelike process on outer margin of each tarsus, the latter always with a pair of prominent setae on its outer distal margin and claw always with a prominent pair on inner margin of its base, with both pairs generally having expanded tips; areas that look like sensory areas may or may not be present. Anus large or small, distinct or delicate, and variable in position according to species.

The genera included in this tribe may be distinguished by the following keys:

### KEYS TO GENERA OF PHOENICOCOCCINI

#### EGG

a. With a single spine ..... **Phoenicococcus** Cockerell.
**Palmaricoccus,** new genus.

aa. With more than one spine.
b. With two disconnected spines ..... **Platycoccus,** new genus.
bb. With a single group of four or more spines .. **Halimococcus** Cockerell.
**Thysanococcus,** new genus.

#### FIRST STAGE

a. Normally with 3 pairs of setae on anal ring, all distinctly smaller than neighboring setae; with 8 pairs of setae, including anal-ring setae, on posterior abdominal segment; rostralis with two more or less long caudal loops when uncoiled within body ..... **Phoenicococcus** Cockerell.

aa. No setae actually on anal ring; setae considered to be homologous with anal-ring setae present, but not all distinctly smaller than neighboring setae; with not more than six pairs of setae on posterior abdominal segment; rostralis with no more than 1 long caudal loop, but sometimes with 1 or 2 roundish caudal loops also, when uncoiled within body.

b. Pores with distinct partitions almost through tubes; at least 5 pairs of setae each on second to fifth abdominal segments, inclusive; basal segment of antenna with 4 setae, and next segment with at least 2 setae, besides a possible spinelike one; all trochanters with 2 setae each, excluding a minute basal one; anus and anal ring relatively prominent; a more or less distinct bulge or two on each side of body along caudal margin---------- **Palmaricoccus,** new genus.

bb. Pores partitioned only very slightly or not at all through any part of tubes; no more than 4 pairs of setae each on second to fifth abdominal segments, inclusive; basal segment of antenna with no more than 3 setae and next segment with no more than 1 seta, excluding possible spinelike one; all trochanters with only 1 seta each, excluding a minute basal one; anus small, distinct or apparently obscure; anal ring obscure or absent; a bulge along caudal margin of body slight or absent.

c. Mesothoracic spiracles open almost directly to exterior; ventromesal thoracic setae short; antenna of the 6-segmented type, relatively elongate; first and fifth antennal segments with 3 setae each, sixth segment with 7 setae------ **Platycoccus,** new genus.

cc. Mesothoracic spiracles open to exterior through an invaginated tube; ventromesal thoracic setae relatively long; antenna either of the 6-segmented or of the annulated type, if of the 6-segmented type, not relatively elongate; first antennal segment with only 2 setae, fifth with only 1, but sixth with 9 setae

d. External openings of 8-shaped pores practically flush with surface; external openings of mesothoracic spiracular invaginations distinctly away from margin on ventral surface; antenna of the 6-segmented type; 4 or 5 setae, excluding minute basal ones, on each coxa; the inner marginal seta on each trochanter relatively short; anus delicate, more or less difficult to see---------- **Halimococcus** Cockerell.

dd. External openings of 8-shaped pores on sclerotic elevations; external openings of mesothoracic spiracular invaginations distinctly on body margin; antenna of the annulated type; only 2 or 3 setae, excluding minute basal ones, on each coxa; the inner marginal seta on each trochanter relatively long; anus small but distinct--------- **Thysanococcus, new genus.**

SECOND-STAGE FEMALE

a. Not puparial; body does not become thickened and hardened; anal valve absent; anus distinctly on ventral surface; anal ring pronounced; with typically at least one pair, and frequently two pairs, of small but distinct anal-ring setae---------- **Phoenicococcus** Cockerell.

aa. Becomes puparium; body more or less thickened and hardened in puparial state; prominent well-defined anal valve present; anus distinctly on dorsal surface; anal ring insignificant or absent; usually none, but one minute, almost obscure pair of anal-ring setae may be present.

b. 8-shaped pores numerous and distributed in general and irregularly over both surfaces of body or, if not so, comparatively prominent, with their partitions extending more or less through membranous tubes; and in no case with pores possessing a single bar only, having flaring or folded-up sides; with typically 11 pairs of setae on head and 5 or more pairs each on second to fifth abdominal segments, inclusive; with 4 or 5 comparatively large fleshy antennal setae.

**Palmaricoccus,** new genus.

bb. 8-shaped pores not distributed in general and irregularly over either surface of body, comparatively small and with partitions apparently extending not at all or but little into membranous tubes or, if not so, each possessing a single bar only, with flaring or folded-up sides and a tube approximately as sclerotic as the bar; no more than 8 pairs of setae, usually less, on head, and no more than 3 pairs of

setae each on second to fifth abdominal segments, inclusive; with no more than 2 comparatively large fleshy antennal setae or, if these are absent, then antenna with 2 small or minute setae only.

c. Head distinctly prolonged as a rounded projection; body noticeably flat, with derm of dorsal and ventral surfaces in contiguity an appreciable distance within margin, at least in older individuals; with all tubular pores small and delicate and comparatively numerous (more than 400) along margin or submargin of both sides of both surfaces, particularly cephalolaterad of head skeleton; mesothoracic spiracles, with their accompanying quinquelocular pores, in no more than slight depressions_____ **Platycoccus**, new genus.

cc. Head not prolonged; body at least moderately thick; derm of dorsal and ventral surfaces not in contiguity an appreciable distance within margin in individuals of any stage of development; tubular pores either distinctly small, delicate, and comparatively few in number, or at least not numerous (not over 60) along margin or submargin of both sides of both surfaces, or comparatively prominent; if prominent, their tubes approximately as strongly sclerotic as their bars, which possess flaring or folded-up sides; mesothoracic spiracles with at least one or more of their accompanying quinquelocular pores, if present, in distinct pockets, or in deep invaginations from the body margin.

d. Body margin without a fringe; with 10 or more quinquelocular pores associated with each mesothoracic spiracle occurring in at least two distinctly different sizes—small, noninvaginated ones within distinct pockets which open to exterior well within margin on ventral surface, and large, invaginated ones situated outside the pockets; with no quinquelocular pores on body other than those associated with the spiracles; antenna with two minute partially invaginated setae only_____ **Halimococcus** Cockerell.

dd. Body margin with a fringe which sharply separates ventral and dorsal surfaces; with only 1 or 2 subequal quinquelocular pores associated with each mesothoracic spiracle, which with the associated pores are within deep granulate invaginations opening to exterior on body margin; other quinquelocular pores sometimes present along body margin; antenna with at least 1 or 2 comparatively large fleshy noninvaginated setae_____ **Thysanococcus**, new genus.

ADULT FEMALE

a. Entire body margin and ventrosubmargin covered with numerous prominent papillae; each of 2 pairs of spiracles with a group of quinquelocular pores; anus situated far cephalad on ventral surface; a pair of distinct anal-ring setae normally present_____ **Phoenicococcus** Cockerell.

aa. Body margin and submargin of both surfaces devoid of papillae; no quinquelocular pores associated with any spiracle; anus distinctly on dorsal surface; anal-ring setae usually absent, if present, inconspicuous or practically obscure.

b. With 8-shaped pores scattered over both surfaces or at least over venter; each antenna with 4 or 5 prominent fleshy setae. **Palmaricoccus**, new genus.

bb. With 8-shaped pores, except when on posterior abdominal segment, localized in midventral region of body from laterocephalic border of head skeleton to and including fourth abdominal segment, their distribution in any one species distinctly more localized than this; each antenna with no more than two fleshy setae.

c. Head distinctly prolonged as a rounded projection. **Platycoccus**, new genus.

cc. Head not prolonged at all.

d. With all 8-shaped pores localized mesad of spiracles, with no deep fold or suture extending from rostrum toward each mesothoracic spiracle; with no plates or squamulae on anal segment; each antenna limited to two minute partially invaginated setae; anus minute and difficult to see; anal ring absent_____ **Halimococcus** Cockerell.

dd. Except for those on anal segment, 8-shaped pores localized directly mesad of spiracles and with a distinct fold or suture extending from rostrum towards each mesothoracic spiracle, or, except for those on anal segment, 8-shaped pores located on the first three segments caudad of metathoracic spiracles; 2 to 6 pairs of small 8-shaped pores along caudal margin of anal segment, which also may possess plates or squamulae; each antenna with either 1 or 2 prominent fleshy setae; anus at least distinct; anal ring present though small.
**Thysanococcus**, new genus.

SECOND-STAGE MALE

a. With prominent anal ring; with normally three pairs of anal-ring setae.
**Phoenicococcus** Cockerell.

aa. Anal ring reduced in size; anal-ring setae absent.

b. Tubular pores rather numerous (at least 100 present), scattered over at least one surface of body and never asymmetrical in type, that is, with bulla issuing from one side of bar.

c. Typically one or more pairs of spiracular pores present; a row of mesal setae each on dorsal and ventral surfaces of abdomen.
**Palmaricoccus**, new genus.

cc. Spiracular pores absent; a row of mesal setae absent on both surfaces of abdomen ..... **Platycoccus**, new genus.

bb. Tubular pores apparently absent or few in number (8 or less) or, if comparatively numerous, 100 or more occurring in a distinct row along ventral margin or submargin of body, the majority of the asymmetrical type.

d. Tubular pores apparently absent or very few in number and restricted to head and the two posterior abdominal segments or to margin of abdomen ..... **Halimococcus** Cockerell.

dd. Tubular pores comparatively numerous, restricted to a row extending practically around body.
**Thysanococcus**, new genus.

ADULT MALE

a. No more than 15 setae on club of antenna; 6 setae only, all slender, on each metathoracic tibia and tarsus together, and two or more prominent clear areas, probably sensory in function, on tibia and tarsus together of each leg ..... **Phoenicococcus** Cockerell.

aa. Thirty or more setae on club of antenna; at least 12 setae, either none or only some of them slender in form, on each metathoracic tibia and tarsus together, and apparently no sensory areas on tibia and tarsus of any leg.

b. With one pair of eyes only.

c. Four pairs of setae on anal segment; at least 3 setae on basal, and at least 2 setae on second antennal segment.
**Palmaricoccus**, new genus.

cc. Three pairs of setae only on anal segment, only 2 setae on basal, and no setae on second antennal segment.
**Platycoccus**, new genus.

bb. With two pairs of eyes.

d. Only 3 pairs of setae on anal segment; club of antenna stout, with no more than four segments, all of which lack spicules; metathoracic tibia with no more than 10 setae, none of which are long and spinelike ..... **Halimococcus** Cockerell.

dd. Four pairs of setae on anal segment; club of antenna elongate, with eight segments, all possessing numerous spicules; metathoracic tibia with about 25 setae, practically all of which are long and spinelike ..... **Thysanococcus**, new genus.

### Genus PHOENICOCOCCUS Cockerell

#### First Stage

Body more or less elongate elliptical, with 1 or 2 small characteristic bulges on each side along caudal margin of posterior end; distinctly flat in living individuals; segmentation well defined except possibly on ventral surface of prothorax and anterior section of mesothorax; more or less membranous cephalad, but abdominal segments progressively more sclerotic posteriorward, especially so toward maturity

of instar. 8-shaped pores comparatively prominent, subequal, with partitions extending nearly, if not quite, through tubes; bars closely joined, though readily distinguished apart; bullae distinct but delicate, external openings flush with surface; typically 10 pairs present, limited to marginal, submarginal, and dorsomesal regions of body. A single quinquelocular pore normally associated with each of 4 spiracles. No invaginated tubes between tracheae and external openings of spiracles; spiraculariae elongate, strongly sclerotic, subequal. Clear area present laterad of each metathoracic coxa. Typically 12 pairs of setae on head, including a frontal pair on ventral surface between arms of head skeleton, 4 pairs on prothorax, 7 pairs each on mesothorax and metathorax, 2 pairs on first abdominal, 5 pairs each on second to seventh abdominal, and 7 pairs on posterior abdominal segment including those on anal ring. Antenna of the 6-segmented type; basal segment more than twice as broad as any other; apical segment moderately elongate. Antennal setae occurring typically as follows: 4 slender setae on basal segment; 2 slender setae and a spinelike process on distal margin of second segment; 3 slender setae on third segment; 1 fleshy seta on fourth segment; 2 slender and 1 fleshy setae on fifth segment; 4 slender and 5 fleshy setae on apical segment. Rostrum with apparently 3 pairs of small setae, 2 pairs distinctly apical and 1 pair distinctly basal in position; rostralis with 2 long caudal loops and 1 long cephalic loop, besides the characteristic small cephalic loop, when uncoiled within body. Legs moderately slender; neither trochanter and femur nor tibia and tarsus fused. Leg setae occurring typically as follows: 6, including minute basal one, on procoxa; 5, including minute basal one, on each of other coxae; 3 on trochanter, including minute basal one and a comparatively long one on inner margin; none on femur or tibia; 3 and a spinelike process on tarsus; 2 on claw. Anus on ventrocaudal margin; anal ring pronounced and typically with 3 pairs of small setae. Male instar not puparial.

### Second-Stage Female

Body moderately elliptical, with a slight broad bulge on each side of mesothorax; general outline continued evenly around posterior end; segmentation distinct except on ventral surface of head, prothorax, and mesothorax; slightly sclerotic throughout even in younger specimens. With rather acutely pointed papillae, more readily observed in younger individuals, along margin of both surfaces and submargin of ventral surface. Tubular pores restricted to the ordinary 8-shaped kind; in structure essentially as in first stage of this genus; scattered on head but much the larger number along margin of both surfaces and submargin of ventral surface. Quinquelocular pores associated with both pairs of spiracles only, noninvaginated, subequal; typically 1 to 4 associated with each of four spiracles. Spiracles and associated pores open practically on surface; spiraculariae elongate, strongly sclerotic, subequal. Body setae varying in size, occurrence, and less so in position; typically 14 pairs on head, 6 pairs on prothorax, 3 pairs on anterior section of mesothorax, 7 pairs on posterior section of mesothorax, 9 pairs on metathorax, 2 pairs on first abdominal segment, and either 4 or 5 pairs on each remaining abdominal segment, excluding those on anal ring. Antenna irregular in form; with a slightly elevated membranous base and a sclerotic distal part having a central sunken area from which issue 5 fleshy setae. Rostrum with 3 distinct pairs of setae, 1 pair basad and other 2 pairs distad in position; rostralis with 2 long caudal loops, 1 long cephalic loop, and the characteristic small cephalic loop, when uncoiled within body. Anal valve absent; anus comparatively prominent and well up on ventral surface; anal ring pronounced, with typically from none to 2 pairs of setae. Instar not puparial.

### Adult Female

Body normally moderately elliptical at first, becoming rounder as full development is approached; general outline continued evenly around posterior end; segmentation obscure except on ventromesal region of thorax and abdomen; in younger specimens, derm slightly sclerotic, in older ones, dorsal and lateral surfaces strongly sclerotic, ventral surface lightly sclerotic. Entire margin and submargin of ventral surface and cephalic and caudal regions of dorsal surface thickly studded with papillae, giving surface a sclerotic appearance; papillae small or prominent, blunt, spinelike or platelike; apical margins of papillae may be irregularly toothed or serrated. 8-shaped pores present, distinct, though small; partitions through bars and tubes practically complete; bars can be distinguished apart; bullae delicate; external openings flush with surface. 8-shaped pores comparatively numerous, scattered over both surfaces, but less abundant on

dorsum; smallest situated ventromesally, next in size dorsomesally, largest marginally on both surfaces and submarginally on ventral surface; some variation in number and position. Quinquelocular pores associated with both pairs of spiracles, and absent elsewhere; subequal, noninvaginated, irregularly scattered; varying appreciably in number, a range of from 6 to 30 and 1 to 15 around the mesothoracic and metathoracic spiracles, respectively, having been observed. Spiracles and associated quinquelocular pores flush with surface; spiracullariae elongate, strongly sclerotic, subequal. Body setae varying in size, position, and occurrence; none prominent; typically about 20 pairs on head, 40 pairs on thorax, and 50 pairs on abdomen. Antenna irregular in form; with a slightly elevated membranous base and a strongly sclerotic distal piece having a central sunken area from which issue 5 fleshy setae. Rostrum with 3 distinct pairs of setae, 1 distinctly basad and other 2 distinctly apical in position; rostralis typically with 2 long caudal loops, 1 long cephalic loop, and characteristic small cephalic loop, when uncoiled within body. Anal segment well up on ventral surface; not sclerotic; anus moderately prominent; distinct anal ring present, typically possessing one pair of setae.

### Second-Stage Male

Body moderately to elongate elliptical, and about equally rounded at both ends; segmentation well defined except on ventral surface of head, prothorax, and mesothorax; more or less membranous throughout. Papillae present, small, mostly spinelike and scarce. With ordinary 8-shaped tubular pores only; more slender than, but in structural details essentially as, in second-stage female; in distribution essentially as in second-stage female except less numerous marginally on thorax but more numerous mesally on both surfaces of thorax and abdomen. Typically none or one quinquelocular pore associated with each mesothoracic, but no pores associated with metathoracic spiracles; no other quinquelocular or any other type of pore present. Spiracles and quinquelocular pores flush with surface; spiracullariae distinctly elongate, strongly sclerotic, subequal. Body setae except in a few minor respects as in second-stage female. Antenna irregular in form; with elevated membranous base and sclerotic distal part without a sunken area; with apparently a minute, slender seta on membranous base and five fleshy setae and a pair of small setae on distal part. Rostrum and rostralis essentially as in second-stage female, except that three larger loops are smaller. Vestigial legs usually in evidence. Anus on or near ventrocaudal margin; pronounced anal ring, usually possessing 1 to 3 pairs of very small setae.

### Adult Male

Body elongate elliptical, with posterior end occurring as a curving, slightly stout rapierlike projection; segmentation of all segments distinct; ventromesal surface of head with a roundish mildly sclerotic area; eighth abdominal and anal segments characteristically mildly sclerotic except near intersegmental sutures; body membranous elsewhere. Vestiges of thoracic wing framework and wings absent. Spiracullariae elongate, largest diameter around spiracles, tapering toward inner ends, strongly sclerotic, subequal. Typically 12 pairs of setae on head, 6 pairs on prothorax, 7 pairs on mesothorax, 6 pairs on metathorax, 2 pairs on first abdominal, 3 pairs each on second and third abdominal, 4 pairs each on fourth and fifth abdominal, 5 pairs each on sixth and seventh abdominal, and 4 pairs each on eighth abdominal and anal segments. Antenna with 2 stout basal segments, the second one not twice as long as broad and with a club apparently composed of 5 segments; apex of distal segment of club blunt and capped by a characteristic rounded knob; with slender setae on each of 2 basal segments, 2 slender setae on each of next 2 segments, 1 fleshy seta on each of following 2 segments, and 4 fleshy and 4 slender setae on apical segment. A single pair of eyes, marginal in position. Head skeleton practically absent, though delicate differentiated areas may be evident, possibly extreme vestiges of parts of head skeleton; invagination leading to alimentary tube distinct. Rostrum absent. Legs subequal except tibia and tarsus of each metathoracic pair stouter than those of the other legs; 4 or 5 small slender setae, besides the minute basal one, on each coxa; 1 short and 1 long slender seta, besides the minute basal one, on each trochanter; no setae on prothoracic femur and tibia; no setae on mesothoracic femur and 1 small slender seta on mesothoracic tibia; 2 small slender setae each on metathoracic femur and tibia; 4 and 2 small slender setae on each tarsus and claw, respectively; distinct roundish or suboval differentiated areas, apparently sensory structures, on metathoracic tibia and on tarsus of all three pairs of legs. Anus distinct, well caudad of cephalic border of ninth abdominal segment.

Type of genus, *Phoenicococcus marlatti* Cockerell.

PHOENICOCOCCUS MARLATTI Cockerell (*1, pp. 262–263; 13*)

Material collected by the writer on the date palm (*Phoenix dactylifera*) in southern California. At all times of the year the majority of the insects are found below the fiber, on the white tissue.

EGG

(FIG. 5, *E*)

Ovoviviparous. Spine moderately sclerotic.

FIRST STAGE

(Figs. 2 and 5, *C* and *D*)

*Body.*—Distinctly sclerotic areas on venter cephalolaterad of head skeleton and caudomesad of rostrum. Usually a distinct furca on meson between mesothorax and metathorax, and a pair of delicate furcae near meson between the two sections of metathorax. Clear area laterad of each metathoracic coxa, delicate; varying in form and size, but apparently always present. Twenty newly hatched individuals, average: Length 0.33 mm, width 0.15 mm; the smallest 0.30 mm long, 0.13 mm wide; the largest 0.35 mm long, 0.16 mm wide. Ten fully developed individuals, average: Length 0.38 mm, width 0.19 mm; the smallest 0.35 mm long, 0.18 mm wide; the largest 0.42 mm long, 0.21 mm wide.

*Pores.*—Typically 10 pairs of 8-shaped pores present, as follows: 2 more or less marginal pairs on head; 1 marginal pair laterad of each pair of spiracles and on second, fifth, and eighth abdominal segments, and 1 dorsomesal pair each on posterior section of mesothorax, metathorax, and second abdominal segment. 8-shaped pores increase slightly in size posteriorward; all fairly stable in occurrence and position except the dorsomesal pairs, in which, of 40 individuals examined, 16 possessed the 3 pairs, 19 lacked a pore on one or both sides of metathorax, 1 on both sides of metathorax and also on second abdominal segment, 1 on one side of mesothorax, and 3 on one side of both mesothorax and metathorax. A single quinquelocular pore associated with each of 4 spiracles; this pore present on one or both sides of mesothorax in 38, and of metathorax in 29, of above-mentioned 40 individuals.

*Spiracles.*—Each spiracularia with two slight constrictions.

*Body setae.*—Somewhat less fixed in position on head and thorax than on abdomen. In number and position typically as follows: Head with 4 ventromesal pairs, of which first 3 caudal pairs are distinctly larger than all other head setae, 1 frontal pair on ventral surface between arms of head skeleton, 3 pairs in near vicinity of eyes, and 4 dorsomesal pairs; prothorax, 3 marginal pairs and 1 dorsomesal pair; anterior section of mesothorax, 1 ventromesal pair; posterior section of mesothorax, 3 marginal pairs, 1 lateromesal of dorsum, 1 dorsomesal, and 1 comparatively prominent ventromesal pair; dorsum of metathorax and anterior section of metathorax combined, 3 marginal pairs, 1 lateromesal of dorsum, 1 dorsomesal pair; first abdominal and posterior section of metathorax combined, 2 marginal pairs, 1 dorsomesal, and 1 fairly prominent ventromesal pair; second to seventh abdominal segments, inclusive, each, 2 marginal, 1 ventrosubmarginal, 1 dorsomesal, and 1 ventromesal pair; posterior abdominal segment, 7 pairs, including 4 marginal and 3 pairs on anal ring; in all, 69 pairs present. In one specimen, outer and inner long caudal pairs 58 and 195 microns long, respectively; inner pair extremely delicate toward their apices.

*Antenna.*—All segments and their setae nearly stable in form and size; setae stable in number but somewhat variable in position; fleshy setae of apical segment close against latter, some of them difficult to distinguish.

*Rostralis.*—In two typical specimens, 1.41 and 1.46 mm long, respectively, or four times or more the length of body.

*Legs.*—All setae and tibial spinelike processes practically stable in form and occurrence and, except apparently for coxal setae, practically stable in position.

*Anal ring.*—Cephalic margin not sharply defined; the 3 pairs of setae comparatively small, the caudal pair being minute and not always distinguished.

*Exuviation.*—In both sexes the break occurs cephalad of the antennae and extends along lateral margins to about as far as metathoracic legs; the ventral skin then turns back on the caudal region like a door.

*Living specimens.*—Pale pink at first; flattened; eventually becoming covered with a loose mass of white filaments; pale and shiny before molting.

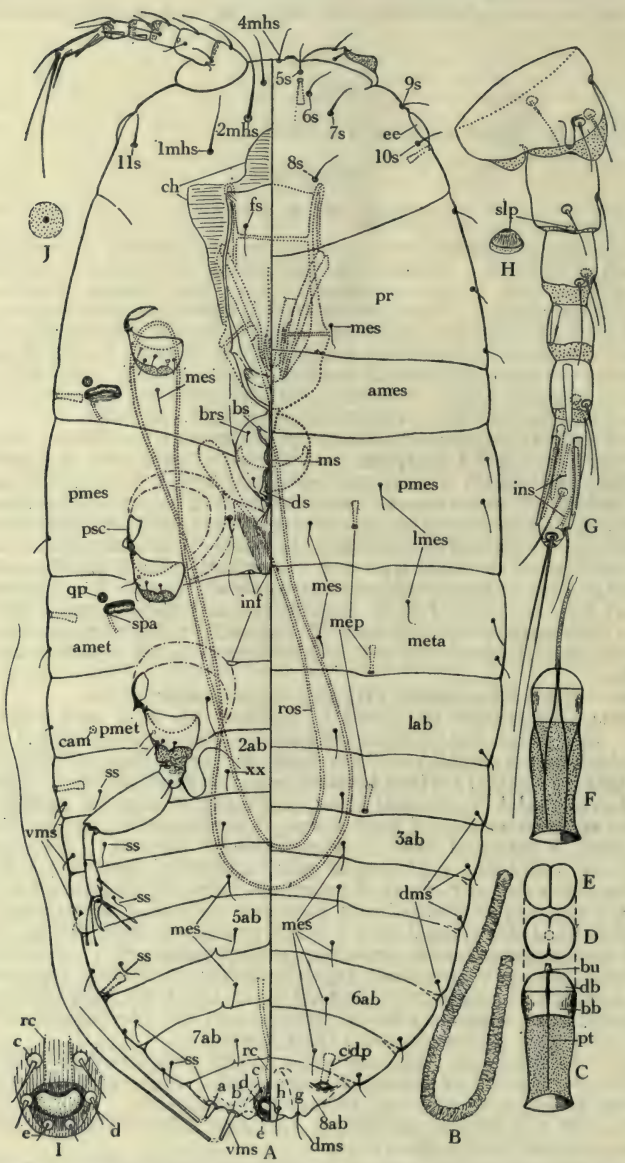


FIGURE 2.—*Phoenicococcus marlatti*, first-stage nymph: *A*, Body, dorsal and ventral, × 400; *B*, crumena, before entrance of rostralis, and consequent expansion, × 400; *C, D, E, F*, 8-shaped pore, through center, cross sections through inner margin of distal bar and tube, and appearance beyond center, respectively, × 3,000; *G*, antenna, ventral, × 1,000; *H*, spinelike structure on distal margin of second antennal segment, × 3,000; *I*, anal ring, × 1,200; *J*, clear area on venter laterad of each metathoracic coxa, × 2,000.

### SECOND-STAGE FEMALE

(Fig. 3)

*Body.*—Thoracic furcae present, essentially as in first stage. Papillae mostly quite small, typically subtriangular, but ranging from very minute to comparatively broad and flat around spiracles; typically numerous along cephalic and caudal margins and in vicinity of spiracles, sparsely scattered elsewhere; variable in abundance and extent, more plentiful around mesothoracic than around metathoracic spiracles, may be almost absent around latter. Toward maturity of instar the entire body margin becomes comparatively thick and smooth, obscuring papillae. A rather large newly molted individual 0.39 mm long and 0.23 mm wide; a rather small one 0.35 mm long and 0.20 mm wide. A rather large, fully developed individual 0.78 mm long and 0.48 mm wide; a rather small one 0.51 mm long and 0.36 mm wide.

*Pores.*—The number and position of 8-shaped pores varying, more so on head and thorax than on abdomen. The 8-shaped pores occurring typically as follows: 12 scattered pairs on head; 7 or 8 marginal pairs, and an equal number of ventrosubmarginal pairs, on prothorax and mesothorax together; 2 pairs on or near margin of each of remaining segments down to and including fifth abdominal one; 1 marginal pair each on sixth, seventh, and posterior abdominal segments; 1 to 3 mesal pairs each on dorsum and venter of thorax; in all, 46 pairs present. The number of quinquelocular pores noticeably unstable; for example, one individual possessed 10 and 11, 7 and 6 associated with mesothoracic and metathoracic spiracles, respectively, whereas another individual possessed only a single pore to each of 4 spiracles; usually 2 or 4 and 1 or 2 associated with each mesothoracic and metathoracic spiracle, respectively.

*Spiracles.*—Each pair typically surrounded by a varying number of curving rows of irregularly formed papillae, mostly broad and shallow, especially the more lateral ones nearest spiracles; mesal ends of spiracularlae usually broadened.

*Body setae.*—Those on head and thorax somewhat variable in position, those on abdomen less so. Their number and position typically as follows: 14 pairs scattered on head, frontal pair absent; 4 marginal, 1 being considered as a lateromesal pair of dorsum, 1 dorsomesal and 1 ventromesal pair on prothorax; 1 lateromesal of dorsum, 1 dorsomesal and 1 ventromesal pair on anterior section of mesothorax; 4 marginal, 1 lateromesal of dorsum, 1 dorsomesal and 1 ventromesal pair on posterior section of mesothorax; 3 marginal, 1 lateromesal of dorsum, 1 dorsomesal, 2 ventrosubmarginal and 2 ventromesal pairs on metathorax; 1 dorsomarginal and 1 dorsomesal pair on first abdominal segment, and, in addition, 1 ventromarginal, 1 ventrosubmarginal, and 1 ventromesal pair on each of second to seventh abdominal segments, inclusive, except for usual absence of ventromesal pair on second abdominal segment; 6 pairs on posterior abdominal segment; in all, 76 pairs present.

*Antenna.*—Membranous base not well differentiated from body derm; sunken area of distal part with an irregular rim; a minute seta usually observed on membranous base; five fleshy setae varying in position and size arising from sunken area of distal part; apparently a minute pair of wholly invaginated setae on side of sclerotic distal part.

*Rostralis.*—Length in three typical specimens, 2.30, 2.44, and 2.49 mm, respectively.

*Anal ring.*—Sclerotization less extensive than in first stage. Typically with either 1 or 2 pairs of setae; sometimes with a single seta or even none. The ventromesal pair of setae on posterior abdominal segment considered homologous with the cephalic pair on anal ring of first stage.

*Exuviation.*—Splits immediately caudad of antennae and along margin to near posterior end; ventral skin rolls back to here.

*Living specimens.*—Pale pink; dull in tone at first, but becoming shiny as the molting period approaches; oval; mass of wax usually denser than in first stage. Some specimens in well-protected places outside fiber of host plant producing a fluffy mass of filaments piled high above body; these filaments nearly always eventually blown away, leaving naked body of insect.

### THIRD-STAGE FEMALE

Not identified.

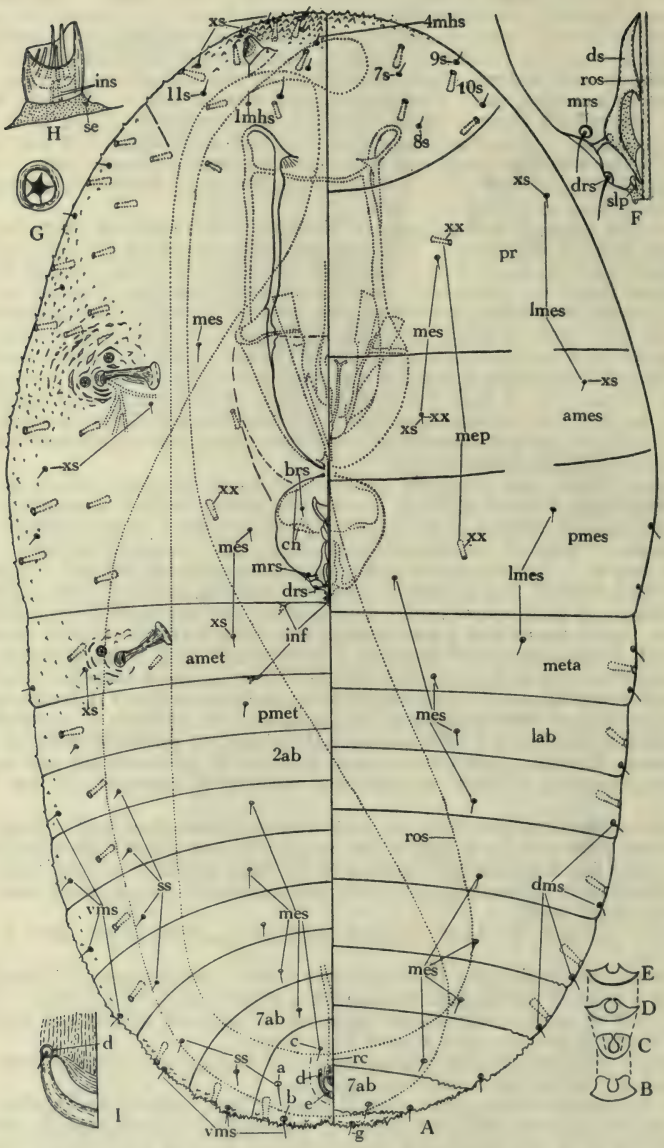


FIGURE 3.—*Phoenicococcus marlatti*, second-stage female: *A*, Body, dorsal and ventral, × 400; *B*, *C*, *D*, *E*, cross sections through the distal, mesal, and apical part of basal, and basal part of basal sclerites of rostrum, respectively, × 600; *F*, venter of distal part of rostrum, × 1,000; *G*, a quinquelocular pore associated with a spiracle, × 2,000; *H*, antenna, × 1,000; *I*, anal ring, × 1,200.

### ADULT FEMALE

(Figs. 4 and 5, *A* and *B*)

*Body.*—At first normally moderately elliptical in outline, flat beneath and moderately convex above in cross section; toward maturity becoming rounder in outline and slightly more convex above in cross section; after egg depletion becoming more or less concave beneath with a tendency to less convexity above; in the closely confined spaces in which it is so abundantly found, the body assuming approximately whatever shape is demanded of it; segmentation distinct on mesoventral region of thorax and abdomen, indicated only by dermal structures elsewhere; clear areas of varying form, most noticeable in older specimens, on mesoventral surface of abdomen, apparently indicating segmentation. Papillae larger, more crowded anteriorly and posteriorly than laterally; their profusion and extent varying; sometimes practically absent near metathoracic spiracles and scarce laterally. With 3 more or less distinct furcae between mesothorax and metathorax and between two sections of metathorax. Average length of 10 newly molted specimens 0.52 mm, width 0.35 mm; a rather large one 0.72 mm long and 0.46 mm wide; a rather small specimen 0.50 mm long and 0.34 mm wide; a fully developed, moderately large, and somewhat flattened specimen 1.3 mm long and 0.98 mm wide; size of fully developed specimens varying considerably.

*Pores.*—In structure 8-shaped pores essentially as in first stage and in second-stage female, but considerably more numerous on all segments; on one side of a typical specimen 156 counted on venter, 48 on dorsum. Number of quinquelocular pores varying greatly; one specimen with a large number had 24 and 30, 14 and 15, and one with a small number had 6 and 7, and 1 each, associated with mesothoracic and metathoracic spiracles, respectively; mesothoracic pores usually more scattered than metathoracic ones.

*Spiracles.*—Essentially as in second-stage female.

*Body setae.*—All relatively small; mesal setae generally smallest; one or more than in second-stage female on all segments of venter except anal segment; setae homologous with those of preceding instars relatively stable in occurrence and position, extra setae unstable in both respects. Number and position of body setae typically as follows: 9 marginal or submarginal, 2 dorsomesal, and 9 ventromesal pairs on head; 3 marginal, 1 lateromesal of dorsum, 1 dorsomesal, 2 ventrosubmarginal, and 3 ventromesal pairs on prothorax; 4 marginal, 2 lateromesal of dorsum, 2 dorsomesal, 3 ventrosubmarginal, and 3 ventromesal pairs on mesothorax; 5 marginal, 1 lateromesal of dorsum, 1 dorsomesal, 4 ventrosubmarginal, and 4 ventromesal pairs on metathorax; 1 dorsomesal pair on first abdominal segment; 2 marginal, 1 dorsomesal, 1 or 2 ventrosubmarginal, and 2, 3, or 4 ventromesal pairs on each of second to seventh abdominal segments, inclusive; in all, from 96 to 110 pairs present.

*Antenna.*—Essentially as in second-stage female but surrounded by numerous flat papillae of irregular outline.

*Rostralis.*—In one typical specimen, 4.92 mm long.

*Anal segment.*—Comparatively reduced in size; with 1 or 2 pairs of 8-shaped pores; with 4 pairs of small subequal setae; anal ring rather narrow and variable in form along its cephalic border; sometimes one or both anal-ring setae absent.

*Living specimens.*—Dorsum dull pinkish red at first, becoming shiny dark reddish or wine red toward full development; venter dull pinkish red at first, and well covered with a thin mat of waxy filaments. In exposed locations at first oval, with dorsum distinctly convex; toward full development dorsum becoming much swollen and rounding considerably onto ventral surface on all sides; mostly naked as usually observed, but occasionally, when protected from wind, some white filaments present piled high above dorsum, as in second-stage female. Behind fiber of host becoming flattened in general toward full development, frequently asymmetrical in form as a result of crowding; a discolored matted mass of waxy filaments nearly always enveloping the body. On forcing back a leaf base of the host to expose the insects, this mat of filaments typically pulled away above, disclosing most noticeably the bright reddish to dark wine-red dorsa of adult female bodies, with only a rim of wax around margins of latter observable; hence, the name "red date scale" that has been used in referring to this insect. After egg deposition the body becomes dull in tone, brown, and leathery in appearance.

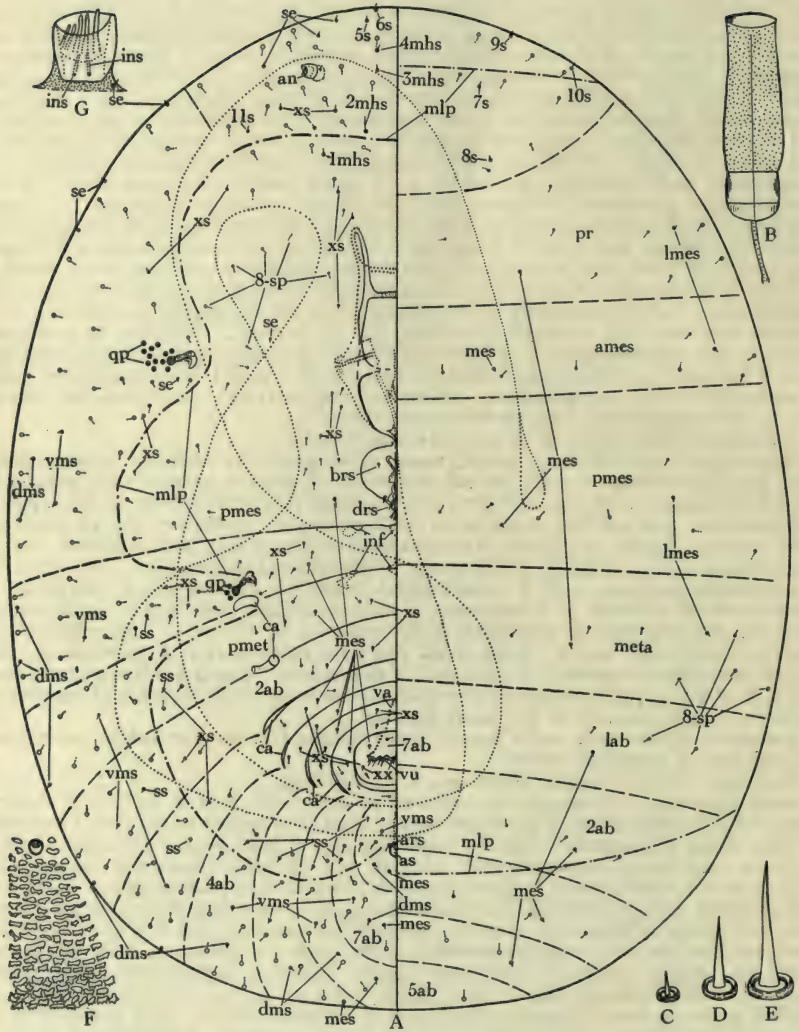


FIGURE 4.—*Phoenicococcus marlatti*, adult female: *A*, Body (partially developed), dorsal and ventral, × 165; *B*, ventromesal abdominal pore, × 3,000; *C*, basal antennal seta, × 2,000; *D*, ventromesal abdominal seta, × 2,000; *E*, ventromarginal seta, × 2,000; *F*, section of ventrocaudal surface of abdomen to show papillae (setae and pores omitted), × 165; *G*, antenna, × 750.

FIGURE 5.—*Phoenicococcus marlatti*: *A*, Adult female, ventrocephalic surface, × 350; *B*, same, anal ring, × 1,200; *C*, first-stage nymph, venter of metathoracic leg, × 1,000; *D*, same, mesothoracic spiracle, × 2,000; *E*, egg spine, lateral aspects, × 1,500.

### SECOND-STAGE MALE

(Fig. 6)

*Body.*—Papillae practically restricted to a narrow fringe along caudal margin. Thoracic furcae present, essentially as in first instar. A rather large newly molted specimen 0.35 mm long and 0.19 mm wide; a rather small one 0.32 mm long and 0.16 mm wide; a typical fully developed specimen 0.41 mm long and 0.20 mm wide.

*Pores.*—A typical specimen possessed the following 8-shaped pores: 8 scattered pairs on both surfaces of head; 1 marginal pair on first abdominal segment; 2 marginal pairs each on prothorax, each section of mesothorax, and second to eighth abdominal segments, inclusive; 3 marginal pairs on metathorax; 1 ventromesal pair each on prothorax, anterior section of mesothorax, and second to fifth abdominal segments, inclusive; 1 ventrosubmarginal and 1 ventromesal pair on posterior section of mesothorax; 1 ventrosubmarginal and 2 ventromesal pairs on anterior section of metathorax; 1 dorsomesal pair on each segment of thorax and first to sixth abdominal segments, inclusive; 1 lateromesal pair of dorsum each on mesothorax and metathorax; in all, 55 pairs present. 8-shaped pores slightly smaller toward meson, perhaps somewhat more so on dorsum. Of 30 specimens, 9 had a quinquelocular pore associated with each mesothoracic spiracle, 9 lacked such a pore on one side and 12 on both sides of mesothorax.

*Body setae.*—Essentially as in second-stage female except for presence of frontal pair on head and 2 pairs of dorsomarginal setae instead of 1 on anal segment, and slightly larger size of second ventromesal pair on head and 1 of marginal pairs on anal segment; in all, 78 pairs present.

*Antenna.*—Comparatively elongate; membranous base just a raised portion of body derm; sclerotic distal part sharply narrowed apically, producing almost the effect of another segment; with 5 fleshy setae of varying sizes and 1 pair of small, apparently wholly evaginated, fleshy setae issuing from lower distal part.

*Rostralis.*—In three typical specimens, 1.3, 1.5, and 1.6 mm long.

*Legs.*—The three pairs nearly always distinct; 2 or 3 segments and as many minute setae can usually be distinguished.

*Anal ring.*—Pronounced; of 15 individuals, 3 possessing 3 pairs of setae, as in first instar, all 12 others lacking 1 to 3 setae from the middle and caudal pairs; in contrast to second-stage female, the cephalic pair considered as actually present on anal ring.

*Exuviation* —Break occurring cephalad of antennae, the derm of both dorsal and ventral surfaces being pushed back to posterior end.

*Living specimens.*—Pale pink; dull in tone at first, shiny toward maturity; wax more dense than in second-stage female, producing a veritable cocoon.

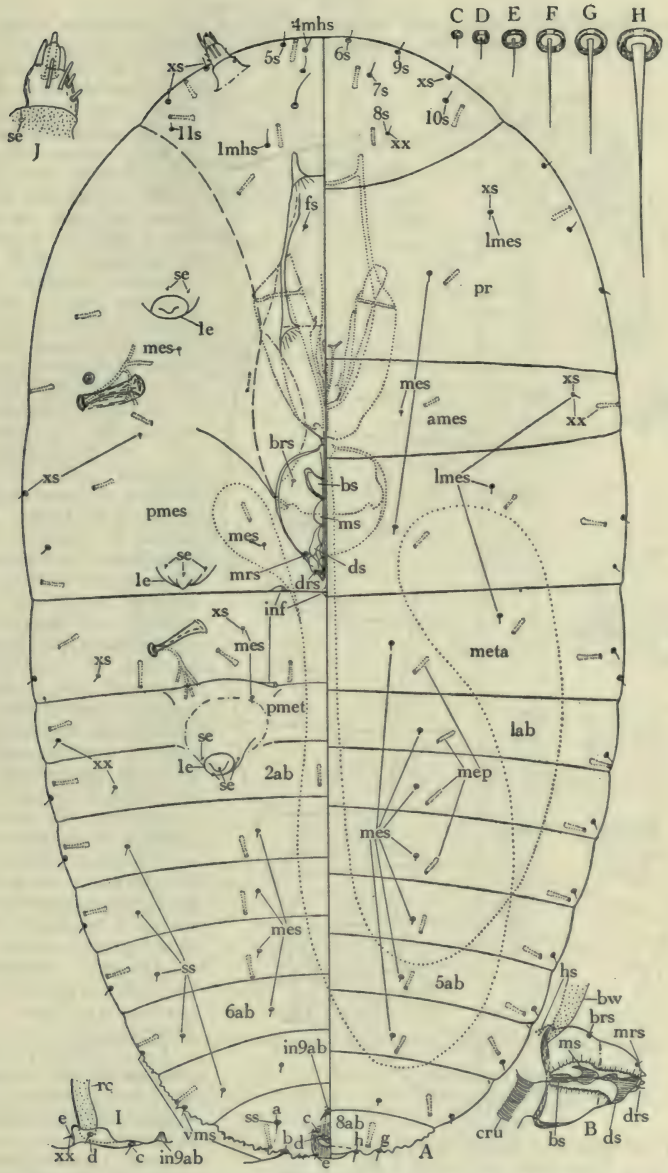


FIGURE 6.—*Phoenicococcus marlatti*, second-stage male: *A*, Body, dorsal and ventral, × 400; *B*, rostrum, lateral aspect, × 400; *C, D, E, F, G, H*, representing setae from various parts of body to illustrate approximately their comparative sizes, × 2,000; *C*, all leg setae; *D*, two caudal pairs of anal-ring setae; *E*, ventromesal cephalic pair of anal-ring and all rostral setae; *F*, all head setae except second ventromesal pair, all marginal and submarginal setae of both dorsal and ventral surfaces of thorax and abdomen except indicated ones mentioned above on anal segment, and all dorsomesal setae; *G*, second pair of ventromesal head setae and ventrosubmarginal pair of setae of anal segment; *H*, ventromarginal pair of setae on anal segment; *I*, anal ring, lateral aspect, × 1,000; *J*, antenna, × 1,000.

### THIRD-STAGE MALE (PREPUPA)

(Fig. 7)

*Body.*—Moderately elliptical; segmentation of all segments more or less defined; varying in size, the average of 10 specimens being 0.37 mm long and 0.18 mm wide.

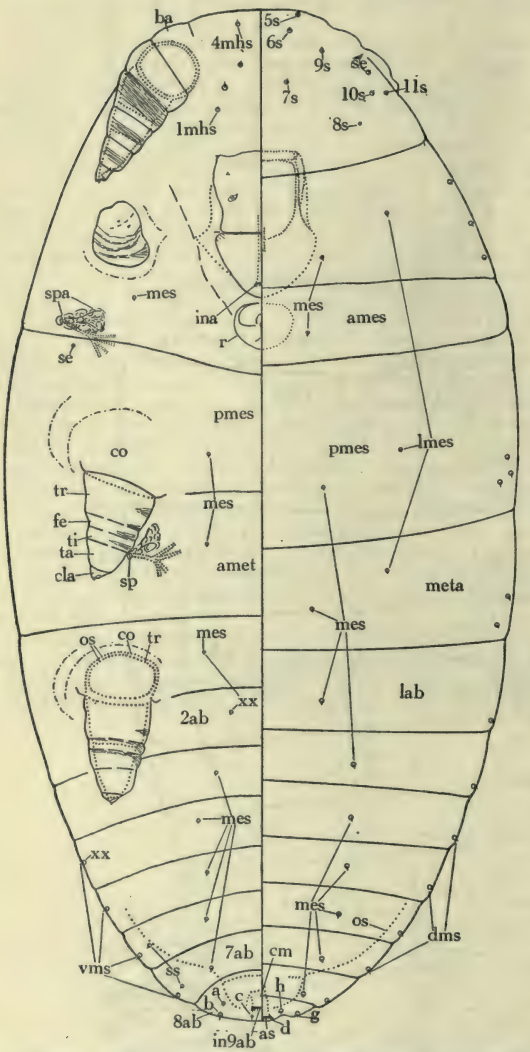


FIGURE 7.—*Phoenicococcus marlatti*, third-stage male (prepupa): Body, dorsal and ventral, × 360.

*Spiracularíae.*—Elongate, with inner ends expanded, lightly sclerotic, subequal.

*Body setae.*—Subequal, shafts short except second ventromesal pair on head, 1 marginal pair on anal segment slightly larger, and 2 mesocaudal pairs on anal segment smaller than the average seta. Body setae occur typically as follows: 12 pairs on head, frontal pair either indistinct or absent; 3 marginal pairs, 1 lateromesal of dorsum, 1 dorsomesal, and apparently 1 ventromesal pair on prothorax; 1 dorsomesal pair on anterior section of mesothorax; 2 or 3 marginal pairs, 1 lateromesal of dorsum, 1 dorsomesal and 1 ventromesal pair on posterior section of mesothorax and on anterior section of metathorax; 1 ventromesal pair on posterior section of metathorax; 1 marginal and 1 dorsomesal pair on each of first to third abdominal segments, inclusive; 1 ventromesal pair on each of second to seventh abdominal segments, inclusive; and, in addition, 1 ventrosubmarginal pair each on posterior section of mesothorax and sixth and seventh abdominal segments; 6 pairs on anal segment; in all, 63 or 64 pairs present.

*Antenna.*—Stocky; with indications of five segments, partially and lightly sclerotic.

*Legs.*—Stocky; with indications of all segments; all segments, except possibly coxae, partially and lightly sclerotic.

*Anal segment.*—Anus distinct, on or quite near caudal margin. Apparent external opening of a membranous tube connecting with ninth abdominal segment of subsequent instar distinct.

*Exuviation.*—Break occurring along dorsomesal line from anterior margin to posterior section of mesothorax.

FOURTH-STAGE MALE (PUPA)

(Fig. 8)

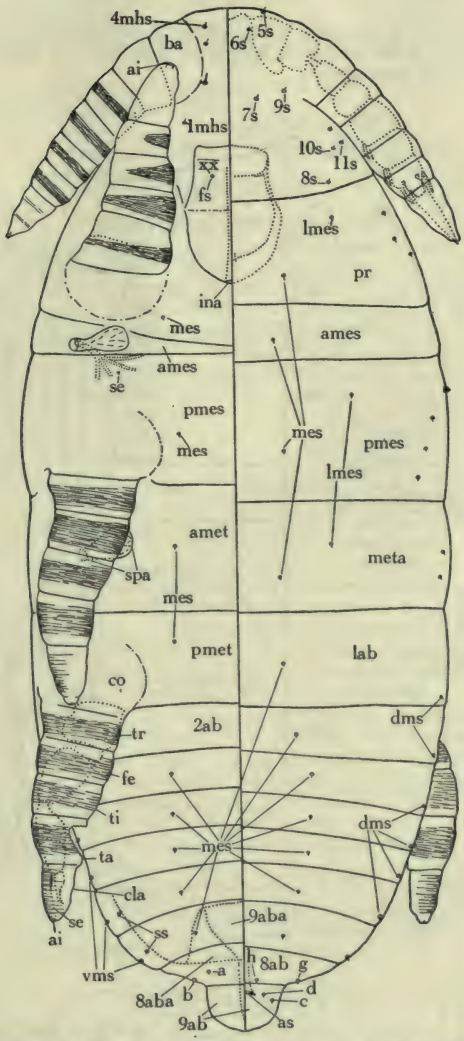


FIGURE 8.—*Phoenicococcus marlatti*, fourth-stage male (pupa): Body, dorsal and ventral, × 360.

*Body.*—Elongate elliptical, with posterior projection noticeably blunt and rounded; segmentation practically complete throughout; varying in size, the average of 10 specimens being 0.38 mm long and 0.16 mm wide.

*Spiracullariae.*—Moderately stout, owing to considerable expansion of inner or mesal ends.

*Body setae.*—Essentially as in preceding instar, except frontal pair on head present and distinct, and ventromesal pair of second abdominal segment usually absent.

*Antenna.*—Stocky, but less so than in preceding instar; with indications of at least seven segments, some of which are partially and clearly sclerotic.

*Legs.*—Essentially as in preceding instar except more elongate, sclerotization of the five distal segments more pronounced, and segmentation more clearly defined; relatively straight.

*Anal segment.*—Anus distinct; situated well caudad of cephalic margin of ninth abdominal segment.

*Exuviation.*—Essentially as in preceding instar.

ADULT MALE

(Fig. 9)

*Body.*—Indentation of sutures along margin pronounced; varying in size, a rather large specimen 0.59 mm long and 0.19 mm wide, a rather small specimen 0.37 mm long and 0.12 mm wide.

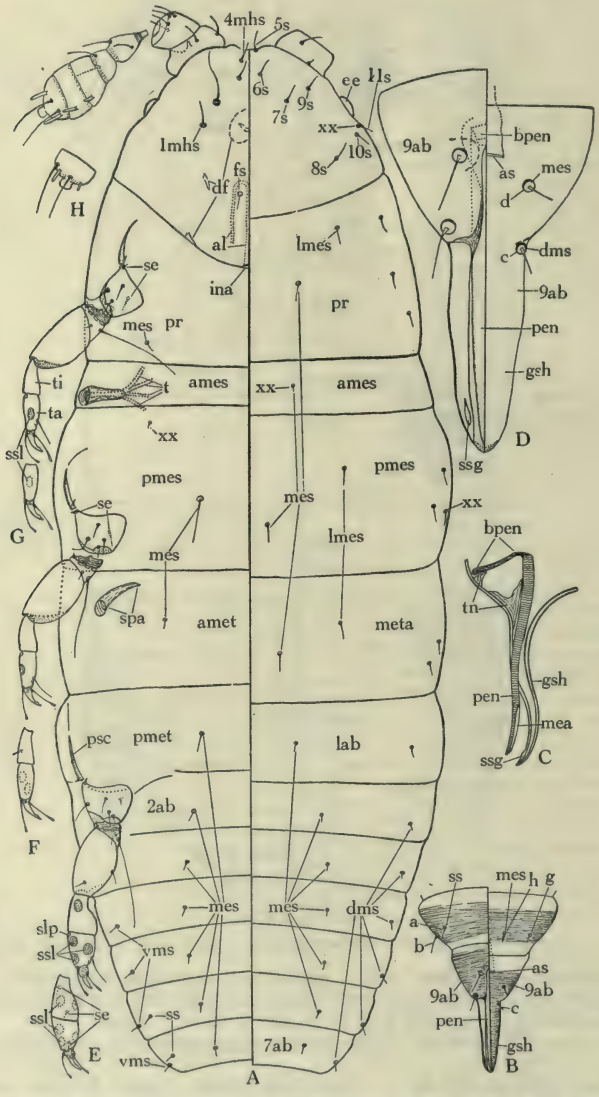


FIGURE 9.—*Phoenicococcus marlatti*, adult male: *A*, Body, dorsal and ventral, × 360; *B*, posterior end, dorsal and ventral, × 360; *C*, lateral aspect of genital structures, × 360; *D*, posterior end, dorsal and ventral, × 1,000; *E*, *F*, *G*, dorsal surfaces of the metathoracic, mesothoracic, and prothoracic tibiae, tarsi, and claws, respectively, × 360; *H*, dorsum of apical segment of antenna, × 360.

*Body setae.*—In distribution and number essentially as in 2 preceding instars except for addition of 2 pairs on ventral surface of anal segment; in structure, shafts distinctly longer than in 2 preceding instars; second ventromesal pair on head and ventromesal pair on posterior section of mesothorax comparatively large; in all, 66 pairs present.

*Antenna*—The 4 distal segments of club compactly united, 1 swollen in appearance, almost oval; distal segment of club capped by a characteristic knob; all slender setae, except 4 distal ones, and all fleshy setae comparatively short.

*Legs.*—Not large; typically with 3 sensory areas on each metathoracic tibia and 2, 3, and 6 on tarsus of each prothoracic, mesothoracic, and metathoracic leg, respectively.

*Living specimens.*—Appearing to naked eye but little larger, but distinctly redder, than first-stage individuals.

### Genus PALMARICOCCUS, new genus

#### First Stage

Body moderately to elongate elliptical; 1 or 2 small bulges on each side along caudal margin of abdomen; segmentation well defined except on ventral surface of head, prothorax, and anterior section of mesothorax; posterior abdominal segment or two sclerotic, remainder of body more or less membranous, although there may be sclerotization laterocephalad of head skeleton. In any one species 8-shaped pores either all of nearly same size and comparatively large, or some comparatively large and others sharply reduced in size; partitions through tubes extending nearly to external openings; bars closely joined but can be distinguished apart; bullae distinct but delicate; external openings flush with surface; typically 12 to 16 pairs present along marginal, submarginal, and dorsomesal regions of body. A single quinquelocular or trilocular pore associated with each mesothoracic, but not with metathoracic spiracles. No invaginated tubes between tracheae and external openings of spiracles; spiracularlae may be elongate and strongly sclerotic or suboval and lightly sclerotic; a subequal clear area present laterad of each metathoracic leg, delicate, variable in form, but usually distinct. Typically either 11 or 12 pairs of setae on head, frontal pair on ventral surface between arms of head skeleton present or absent, 4 pairs on prothorax, 7 pairs on mesothorax, either 7 or 8 pairs on metathorax, 2 pairs on first abdominal segment, 5 pairs each on second to seventh abdominal segments, inclusive, and 6 pairs on posterior abdominal segment. Antenna of the 6-segmented type; basal segment more than twice as broad as any other, apical segment moderately elongate. Antennal setae occurring typically as follows: 4 slender setae on basal segment, 2 slender setae and a spinelike process on second segment; either 3 or 4 slender setae on third segment; either 1 fleshy seta or none on fourth segment; 3 slender setae and 1 fleshy seta on fifth segment; 4 slender and 5 fleshy setae on apical segment. Rostrum with apparently 3 pairs of small apical setae; rostralis either with 1 single long caudal loop or, in addition, with 1 or 2 irregular roundish caudal loops, when uncoiled within body. Legs moderately slender or slightly stout; neither trochanter and femur nor tibia and tarsus fused. Leg setae occurring typically as follows: 6 setae, including minute basal one, on each procoxa and 5, including minute basal one, on each of remaining coxae; 3 setae, including minute basal one and a comparatively long one, on trochanter; either 1 or 2 setae on femur, either 1 or none on tibia, 3 setae and a spinelike process on tarsus, and 2 setae on claw. Anus on caudal margin; anal ring distinct, but no setae definitely on anal ring. Male instar may or may not be puparial.

#### Second-Stage Female

Body moderately elliptical to pyriform; general outline not continued evenly around posterior end, which slightly projects; segmentation of head and thorax obscure, that of abdomen distinct toward posterior end, in young specimens membranous except seventh abdominal segment. Papillae present; prominent and numerous along margin and submargin, and may or may not be scattered plentifully over both surfaces of body. 8-shaped pores always present; of ordinary kind only; varying considerably in size, rather limited in number or numerous, or scattered over body; partitions extending to a greater or less degree through tubes; bars may or may not be difficult to distinguish apart; bullae distinct; external openings not on projections. All quinquelocular pores subequal, noninvaginated, typically 1 to 55 associated with each spiracle, no others on body. Spiracles and quinquelocular pores open on surface or in shallow depressions of surface derm; region about spiracles may or may not be noticeably thickened and rugose; spiracularlae elongate, strongly sclerotic, subequal. Typically either 10 or 11 pairs of setae on head and 2 to 7 pairs on each remaining body segment. Antenna with or without an elevated membranous base, but

always with a sclerotic distal part; the latter may or may not have a central sunken area but always has 4 or 5 fleshy setae and a pair of small setae which may or may not be wholly invaginated. Rostrum with 3 pairs of setae, 1 pair basad and 2 pairs distad in position; rostralis with 1 elongate loop, 2 roundish loops, and the small cephalic loop, when uncoiled within body. A membranous area through which rostralis of adult is forced may or may not be distinct. Anal valve always present; with characteristic markings; lacking pores, but with 3 to 6 pairs of setae; anus centrally or cephalically located on anal valve; anal ring small or indistinct, apparently lacking setae. Becomes puparium; derm of latter may or may not be heavily sclerotic.

### Adult Female

Body moderately to elongate elliptical or pyriform, posterior end distinctly projecting beyond general margin. In both young and old specimens derm membranous except on dorsocaudal part of anal segment, which may be lightly sclerotic; segmentation obscure except on venter of abdomen and on both surfaces of posterior abdominal segments. Papillae present, but not distributed in general over body; at most restricted to immediate vicinity of spiracles and ventromesal region of thorax, on which they are inconspicuous, spinelike, or platelike with serrated apical margins, and occur characteristically in irregular rows. 8-shaped pores distinct though small; partitions apparently may or may not extend through tubes; bars can be distinguished apart with difficulty; bullae delicate; external openings may or may not be surrounded by distinctly sclerotic rims; pores scattered over venter or over both surfaces; may be numerous or few in number. No pores associated with spiracles, but quinquelocular pores may be present on sixth abdominal segment. Spiracles flush with surface; spiracullariae elongate, strongly sclerotic, subequal. Body setae small or moderate in size except on anal segment; typically 7 to 12 pairs on head, 19 to 24 pairs on thorax, and 35 to 48 pairs on abdomen. Antenna limited to a single sclerotic piece without a prominent central sunken area, though a very small depression apparently may be present in one species; with 4 or 5 fleshy setae and a pair of small slender setae, which may be wholly or only partially invaginated. Rostrum with apparently 3 minute pairs of setae; rostralis with 1 elongate loop, and the characteristic small cephalic loop, or, in addition, with 2 large roundish loops, when uncoiled within body. Anal segment on both surfaces of posterior end either practically membranous or partially and lightly sclerotic on its caudal portion; with from 2 to 6 pairs of 8-shaped tubular pores on or near caudal margin; with 6 pairs of setae, 3 pairs along ventrocaudal margin being relatively prominent. Anus well up on dorsal surface; moderately prominent; apparently with or without a small anal ring; anal-ring setae apparently absent.

### Second-Stage Male

Body moderately to elongate elliptical; sides may be nearly parallel or midthoracic region may bulge; segmentation obscure except on abdomen or rather distinct throughout except on ventral surface of head, prothorax, and mesothorax; membranous except for possible faint sclerotization of posterior abdominal segment, or lightly sclerotic but increasingly so posteriorward on the 3 or 4 posterior abdominal segments. Papillae practically absent except around spiracles, or abundant marginally and submarginally on both surfaces of body, where they are small and spinelike. 8-shaped pores restricted to ordinary kind; may be only moderately plentiful or comparatively numerous; scattered on both surfaces; partitions extending through bars and more or less through tubes, but may be difficult to distinguish in latter; bullae delicate; external openings apparently flush with surface, but may be surrounded by sclerotic rims. Typically from none to 8 quinquelocular pores associated with each mesothoracic and none to 3 with each metathoracic spiracle; in the latter position a single trilocular or quadrilocular pore may replace a quinquelocular pore normally present; no other quinquelocular or any other pore type present elsewhere on body. Spiracullariae distinctly elongate, strongly sclerotic, subequal. No less than 8 pairs of setae on head; no less than 6 pairs on anal segment, 1 of which is distinctly larger and pair next to it slightly larger than the other body setae, and no less than 3 pairs on each of other body segments, except possibly anterior section of mesothorax and first abdominal segment. Antenna prominent, with 4 or 5 large fleshy setae, or greatly reduced in size, with hardly more than vestiges of setae; if the latter, puparial in form. Rostrum with 3 pairs of minute setae, all more or less apical in position; rostralis with a broad shallow bend and the characteristic small cephalic loop, or with 1 elongate loop, 2 broad rather deep

loops, and the characteristic small cephalic loop, when uncoiled within body. Vestigial legs may or may not be in evidence. Anus prominent; situated on or near caudal margin, which may or may not slightly project here; distinct anal ring; anal-ring setae apparently absent.

### Adult Male [7]

Body elongate elliptical, with posterior end occurring as a moderately slender rapierlike projection; segmentation defined in all segments except anterior section of mesothorax; membranous except posterior abdominal segment and, in addition, possibly a mild sclerotization of a portion of penultimate segment. Vestiges of thoracic wing framework absent, or at most indicated by cephalic and caudal borders of dorsum of mesothorax being unusually well defined, with pronounced depressions. Vestigial wings may or may not be present. Spiraculariae stout or inclined to be elongate, strongly sclerotic, subequal. Body setae approximately as in *Phoenicococcus marlatti* except 2 to 4 pairs each may be absent from head, thorax, and abdomen. Antenna with 2 stout basal segments; second segment not longer than broad; club stout or elongate, composed of 5 to 7 segments; each of 2 basal segments with 2 to 5 slender setae and none or 1 fleshy seta; each of club segments with from 1 to 4 slender and from none to 8 fleshy setae; antennal setae may be comparatively small or prominent. Single pair of eyes, marginal in position. Head skeleton with the merest vestige remaining, or with vestigial parts distinct. Rostrum either absent or vestigial. Legs large, subequal, or metathoracic tibia and tarsus distinctly stouter than the other tibiae and tarsi; with slender and fleshy setae of various sizes on all segments, or slender setae only on each trochanter and femur; with typically 7 to 9 setae on each coxa and 3 on each trochanter, including minute basal seta on each, 3 to 9 on each femur, 3 to 16 on each tibia, 5 to 16 on each tarsus, and 2 on each claw; apparently no definite sensory areas present on any segments. Anus distinct; may be near or on cephalic border of anal segment.

Type of genus, *Palmaricoccus attaleae*, new species.

### Keys to Species of Palmaricoccus

#### FIRST STAGE

a. Only 12 8-shaped tubular pores normally present, with dorsomesal ones absent; spiracular pores trilocular; no seta on fourth antennal segment. **attaleae**, new species.

aa. From 14 to 16 8-shaped tubular pores normally present, including at least 4 pairs of dorsomesal ones; spiracular pores quinquelocular; a prominent fleshy seta on fourth antennal segment.

b. Body comparatively large, typically about 0.36 mm long and 0.16 mm wide; 14 8-shaped tubular pores normally present, dorsomesal ones only slightly smaller than marginal ones; a single pore associated with each of 4 spiracles; mesothoracic spiracular pores about 5 microns in diameter; 1 pair of frontal setae present; 1 seta midventrally located on femur and 1 seta on inner distal margin of tibia; rostralis comparatively long and possessing 1 long caudal loop and 2 or more large roundish loops, when uncoiled within body, besides the characteristic small cephalic loop---------- **pritchardiae**, new species.

bb. Body comparatively small, typically about 0.22 mm long and 0.13 mm wide; 16 8-shaped pores normally present, with dorsomesal and dorsosubmarginal ones distinctly smaller than marginal pores; no pores associated with metathorac spiracles; mesothoracic spiracular pores about 3 microns wide; frontal setae absent; no seta midventrally situated on femur and no setae at all on tibia; rostralis not long, with 1 long caudal loop and the characteristic small cephalic loop only, when uncoiled within body---------- **nesiotes** Laing.

#### SECOND-STAGE FEMALE

a. With 8-shaped pores distributed in general over body, dorsomesal pores being only slightly smaller than the others; distinct platelike thickenings of irregular form about all 4 spiracular external openings; with 4 fleshy antennal setae, reduced in size and arising from a sunken area; anal valve with only 3 pairs of setae, all comparatively large, rather stout, and subequal; anus located centrally on anal valve-------- **attaleae**, new species.

[7] Data lacking for one species, and not complete for another.

aa. Majority of 8-shaped pores on or near body margin, the mesal ones on both surfaces considerably smaller than the marginal pores; no distinctly plate-like thickenings around any spiracular opening; all fleshy antennal setae prominent and not arising from a sunken base; anal valve with 6 pairs of setae, 4 of these small or ordinary in size, the remaining 2 pairs, laterad in position, slightly larger, but not stout; anus distinctly cephalad as regards its position on anal valve.

b. A newly molted specimen typically about 0.64 mm long and 0.33 mm wide; caudal margin of posterior end evenly rounded but not projecting; papillae extending from margin considerably mesad on ventral surface; 8-shaped pores numerous (more than 700 on body); typically 30 or more quinquelocular pores associated with each of 4 spiracles, though sometimes as few as 12 or as many as 55 or more may be present around any spiracle; 7 pairs of setae each on fourth, fifth, and sixth abdominal segments; antenna with 5 prominent fleshy setae. **pritchardiae**, new species.

bb. A newly molted specimen typically 0.37 mm long and 0.19 mm wide, thus not much more than half as large as **pritchardiae**; caudal margin of posterior end with a wavy outline and characteristically projecting; papillae rather sharply restricted to marginal and submarginal regions of ventral surface; considerably less than half as many 8-shaped pores (no more than 250 on body, and usually less) as in **pritchardiae**; typically only 4 to 6 quinquelocular pores associated with each mesothoracic and 1 with each metathoracic spiracle; only 6 pairs of setae each on fourth, fifth, and sixth abdominal segments; antenna with only 4 fleshy setae---------- **nesiotes** Laing.

ADULT FEMALE

a. With 8-shaped pores scattered promiscuously over both surfaces of body; with an irregular row of quinquelocular pores on sixth abdominal segment; fleshy antennal setae shorter, or at least no longer, than antenna itself; all six pairs of setae on anal segment distinctly larger than the other body setae---------- **attaleae**, new species.

aa. With 8-shaped pores scattered promiscuously, but practically confined to ventral surface; no quinquelocular pores on body; 4 of antennal setae at least twice the length of antenna itself; with only 3 pairs of setae on anal segment distinctly larger than the other body setae.

b. Body suboval to pyriform, typically 1.1 mm long and 0.74 mm wide; typically with no less than 300 8-shaped pores on body; 4 of antennal setae at least 3 times length of antenna itself. **pritchardiae**, new species.

bb. Body elongate elliptical, typically 0.67 mm long and 0.30 mm wide; typically with no more than 60 8-shaped pores on body; none of antennal setae more than about twice length of antenna itself. **nesiotes** Laing.

SECOND-STAGE MALE

a. Remains within first-stage body, which is puparial; papillae absent; 8-shaped pores minute, rather difficult to distinguish; antennae hardly more than slightly sclerotic thickenings; all antennal setae distinctly vestigial---------- **attaleae**, new species.

aa. Bursts from first-stage body, which is not puparial; numerous distinct papillae around body margin; 8-shaped pores not minute, readily observable; antennae not only projecting well above the surface as distinct tubercles, but apparently segmented and each with 4 or 5 prominent fleshy setae.

b. Body typically 0.40 mm long and 0.23 mm wide; typically with 4 to 8 quinquelocular pores associated with each mesothoracic and 1 to 3 with each metathoracic spiracle; a pair of frontal setae present between arms of head skeleton---------- **pritchardiae**, new species.

bb. Body typically 0.29 mm long and 0.17 mm wide; typically with 1 to 3 quinquelocular pores associated with each mesothoracic, and usually none but occasionally 1 quinquelocular pore associated with each metathoracic spiracle; frontal setae absent---------- **nesiotes** Laing.

ADULT MALE

a. Wings entirely lacking; club of antenna stout, 5-segmented, distal segment sharply reduced in breadth; segments of each metathoracic leg with typically the following number of slender and fleshy setae, respectively, excluding minute basal ones on coxae and trochanters: Coxa 5 and 1, trochanter 2 and none, femur 4 and 1, tibia 5 and 2, tarsus 4 and 5. **attaleae**, new species.

aa. Vestigial wings present and distinct; club of antenna 7-segmented, distal segment not appreciably reduced in breadth; segments of each metathoracic leg with typically the following number of slender and fleshy setae, respectively, excluding minute basal ones on coxae and trochanters: Coxa 4 and 4, trochanter 1 and 2, femur 4 and 5, tibia 8 and 8, tarsus 4 and 12. **nesiotes** Laing.

PALMARICOCCUS ATTALEAE, new species

Material collected by G. F. Ferris in 1925 near Manzanillo, State of Colima, west coast of Mexico, on the old fruit of the "coquito palm" (*Attalea cohune*) lying on the ground beneath the trees.

EGG

(Fig. 10, *F*)

Oviparous. Spine strongly sclerotic.

FIRST STAGE

(Fig. 10, *A–E*)

*Body.*—Elongate elliptical. Sclerotic areas near head skeleton usually obscure or absent. A distinct furca on meson between mesothoracic and metathoracic segments. The 2 posterior abdominal segments relatively strongly sclerotic. Typical newly hatched specimen 0.27 mm long and 0.12 mm wide; fully developed female moderately sclerotic, typically 0.50 mm long and 0.27 mm wide. Male instar becomes puparium; strongly sclerotic; typically 0.39 mm long and 0.20 mm wide.

*Pores.*—Typically with 12 pairs of 8-shaped pores as follows: 2 marginal pairs on head; a single marginal pair each on prothorax, anterior sections of both mesothorax and metathorax, and first, third, sixth, seventh, and posterior abdominal segments; submarginally, a pair each on venter of third and fifth abdominal segments. 8-shaped pores slightly larger posteriorward. A single trilocular pore associated with each of four spiracles.

*Spiracles.*—Spiraculariae suboval, lightly sclerotic, subequal; with granulate areas on each side of spiracular external openings.

*Body setae.*—In distribution essentially as in *Phoenicococcus marlatti*, usually with the addition of a minute pair on venter of anterior section of metathorax mesad of spiracles, and one less pair on posterior abdominal segment; in all, 69 pairs present. In one specimen, outer and inner long caudal pairs 53 and 203 microns long, respectively.

*Antenna.*—With 4 setae on third segment, none on fourth, and 3 slender setae on fifth segment; otherwise essentially as in *Phoenicococcus marlatti.*

*Rostralis.*—Length in two typical specimens, 0.63 and 0.72 mm, respectively.

*Legs.*—Essentially as in *Phoenicococcus marlatti* except for presence of two setae on femur.

*Anal ring.*—Reduced in size but apparently present. No setae on anal ring, but two pairs near it on ventral surface considered homologous with the middle and cephalic pairs on anal ring in *Phoenicococcus marlatti.*

*Exuviation.*—In male, break occurring ventrally on suture between sixth and seventh abdominal segments and extending along this suture onto dorsal surface until usually but a small connection remains; frequently in mounted specimens the caudal end entirely separated from puparium. In female, derm swollen from growth of subsequent instar bursting in an irregular manner.

*Dried material.*—Frequently found in crevices; body mostly bright brown; apparently naked.

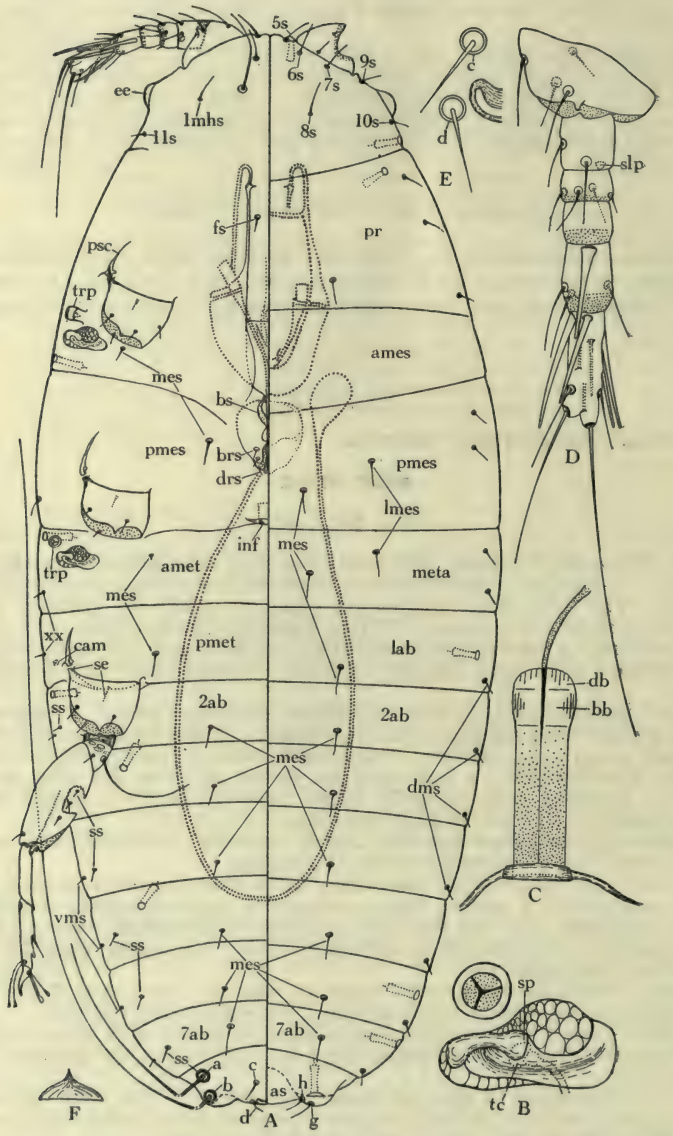


FIGURE 10.—*Palmaricoccus attaleae: A*, First-stage nymph, body, dorsal and ventral, × 500; *B*, same, mesothoracic spiracle, × 2,000; *C*, same, dorsocaudal pore, × 3,000; *D*, same, antenna, ventral surface, × 1,000; *E*, same, anal-ring and neighboring setae, × 2,000; *F*, egg spine, × 1,500.

### SECOND-STAGE FEMALE

(Figs. 11, 12, *F*, and 13, *A–D*)

*Body.*—Elliptical in younger specimens, pyriform in older ones; segmentation obscure except for the 4 or 5 posterior abdominal segments; in younger specimens derm membranous except on seventh and to some extent on sixth abdominal segments, seventh being strongly sclerotic; sclerotization spreading cephalad, but in decreasing degree, to and including dorsum of fourth abdominal segment before general thickening of entire body wall takes place. Prominent, stout, spinelike, frequently curved papillae, scattered thickly along lateral and cephalic margins of ventral surface, so abundant that, in younger specimens, the derm beneath is obscured; away from these margins papillae becoming smaller, blunter, and fewer in number; fully developed individuals uniformly heavily sclerotic, obscuring the papillae. In older specimens a pair of comparatively large roundish thin areas in body wall laterad of head skeleton penetrated on either side by rostralis of adult. A newly molted specimen 0.36 mm long and 0.25 mm wide; a typical puparium 1.60 mm long and 0.97 mm wide.

*Pores.*—8-shaped pores moderately numerous and scattered over both surfaces except on the 3 or 4 posterior abdominal segments; all small and somewhat elongate, smallest mesad on dorsal surface; partitions extending apparently about half way through tubes; bars readily distinguished apart; on one side of one typical specimen were 82 ventral and 38 dorsal pores, thus roughly twice as many on ventral as on dorsal surface. From 3 to 15 quinquelocular pores associated with each of four spiracles; situated within shallow depressions leading to spiracles or on raised sclerotic pieces studding the depressions.

*Spiracles.*—Both pairs in shallow depressions; distinct, irregularly formed, overlapping sclerotic thickenings or plates cover the sides and surrounding regions of the depressions, giving a rough or rugose appearance to the parts; spiraculariae distinct, slightly enlarged at inner ends.

*Body setae.*—Typically 11 scattered pairs on head; 3 marginal, 1 dorsomesal, and 1 ventromesal pair on prothorax; 3 marginal, 1 dorsomesal, 1 lateromesal of dorsum, and 1 ventromesal pair each on mesothorax and metathorax, and 1 additional marginal pair on metathorax; 1 marginal and 1 dorsomesal pair on first abdominal segment; 1 dorsomarginal, 1 dorsomesal, 1 ventromarginal, 1 ventrosubmarginal, and 1 ventromesal pair on each of second to seventh abdominal segments, inclusive; 3 pairs on anal valve; in all, 64 pairs present.

*Antenna.*—A raised membranous base practically absent; otherwise essentially as in *Phoenicococcus marlatti* except for presence of only 4 fleshy setae and apparently 1 minute slender seta on lateral surface of distal sclerotic part of antenna.

*Rostralis.*—In one typical specimen, 1.8 mm long.

*Anal valve.*—Except basally, covering tissue reticulate in appearance; markings obscured in older specimens; with three pairs of comparatively large, stout setae. Anus centrally located; anal ring apparently present, small and without setae.

*Dried material.*—Puparium reddish to blackish brown around margins and bright brown mesally; leathery in appearance; almost wholly exposed owing to shallow crevices on the old fruit; naked except for occasional slight fringe of whitish waxy matter around body margin; somewhat variable in size and form; moderately flattened; lateral surface bulging or rounded, with no sharp line separating it from the ventral surface; posterior end pointed dorsocaudad.

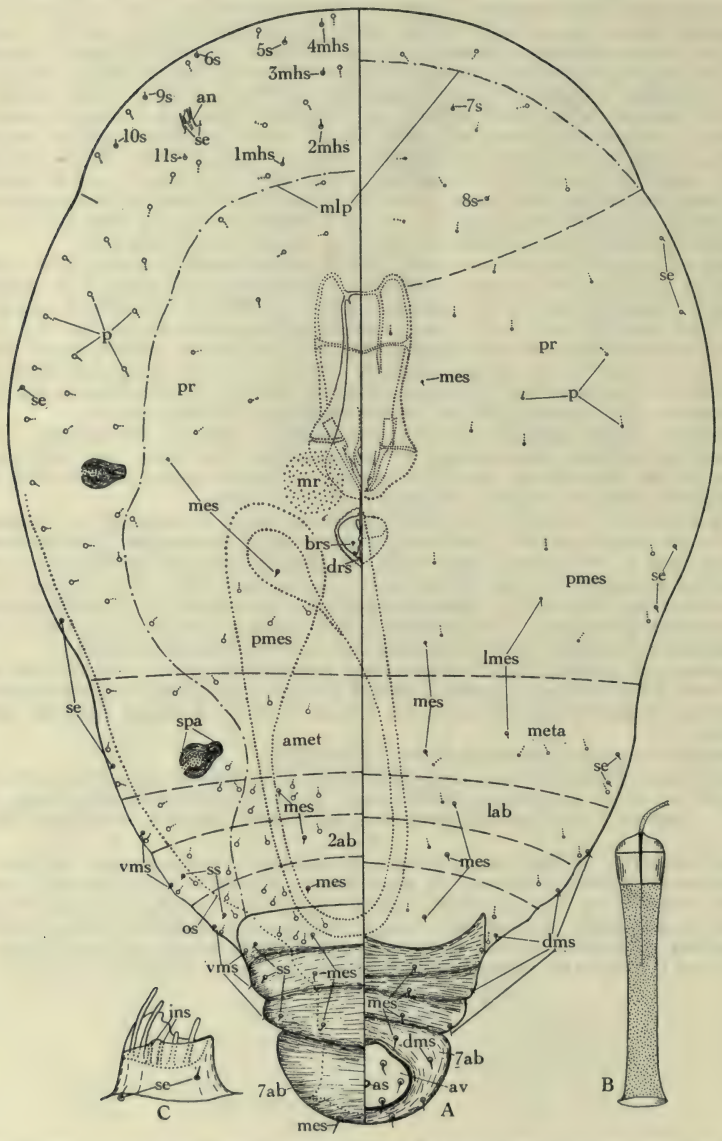


FIGURE 11.—*Palmaricoccus attaleae*, second-stage female: *A*, Body (partially developed), dorsal and ventral, × 150; *B*, 8-shaped pore, × 3,000; *C*, antenna, × 2,000.

### THIRD-STAGE FEMALE

(Fig. 12, *A–E*)

*Body.*—Pyriform; fitting snugly against inner walls of preceding instar; segmentation not distinguishable except for slight indentations along margins of posterior abdominal segments, possibly marking the limits of the latter; membranous but distinct; derm comparatively rigid and rather easily separated from preceding instar; posterior abdominal segments plainly ridged in wavy lines; caudal margin frazzled in all available specimens; no definite structures discernible on dorsal surface; within posterior end apparently a delicate membrane connecting this instar with the developing subsequent instar.

*Pores.*—Moderate number of clear spots scattered over ventral surface; usually in center of each an 8-shaped structure, the inner end of a pore of preceding instar; clear spots apparently thin areas in body wall to accommodate inwardly projecting second-instar pores; this view strengthened on noting occasionally an entire pore lying flat within a clear spot which is formed to suit the pore; not infrequently a clear spot is empty, presumably indicating that a pore has been pulled away in removing it from puparium; the latter showed empty clear spots, too, with uneven margins, apparently indicating that pores have been pulled away.

*Spiracles.*—Each pair peculiar to this instar; spiraculariae elongate, moderately sclerotic, subequal; each with a sclerotic collar around external opening of spiracle, behind which is a short, somewhat expanded chamber, at the farther end of which issues a dense brush of tracheoles characteristically extending cephalad and ending in an enlarged irregular mass of tissue.

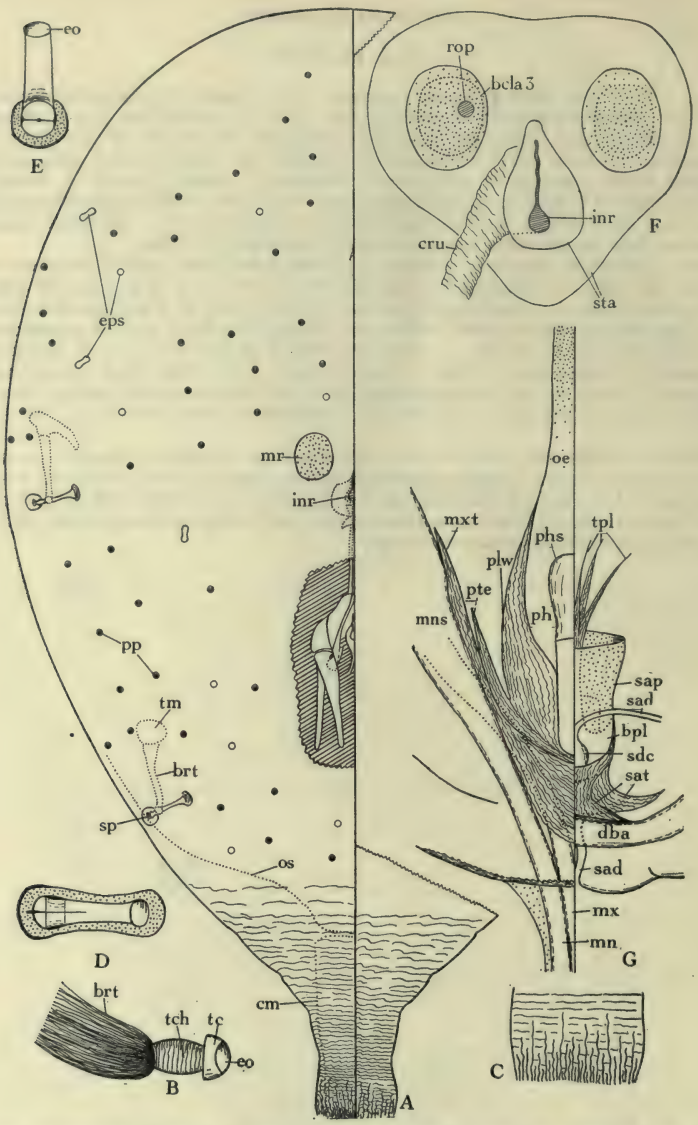


FIGURE 12.—*Palmaricoccus attaleae: A*, Third-stage female, body, dorsal and ventral, × 150; *B*, same, tracheal collar, expanded tracheal chamber, and brush of tracheoles, × 500; *C*, same, caudal margin of posterior end, showing frazzled condition, × 300; *D*, same, full-length pore lying in clear spot, × 1,500; *E*, same, inner end of pore only lying in clear spot, × 1,500; *F*, second-stage female, midventral region, × 300; *G*, adult female, details of part of head-skeleton assemblage, × 1,000.

### ADULT FEMALE

(Figs. 12, *G*, 13, *E*, and 14)

*Body.*—Moderately elliptical to pyriform; segmentation obscure except on both surfaces of the five posterior segments; membranous throughout, including anal segment. A typical rather large specimen 1.07 mm long and 0.82 mm wide; a rather small one 0.85 mm long and 0.55 mm wide.

*Pores.*—8-shaped pores all noticeably small; distributed approximately as in second-stage female, except scarcer on venter of head and for their occurrence on anal segment; partitions extending apparently hardly more than through bars; bars can be distinguished apart; external openings not surrounded by distinctly sclerotic rims; on one side of one typical specimen, 110 and 108 pores counted on venter and dorsum, respectively, thus about equally numerous on both surfaces. Around sixth abdominal segment an irregular band of subequal quinquelocular pores ranging in number typically from 20 to 26; slightly more numerous on ventral than on dorsal surface.

*Spiracles.*—With several small curving rows of faint shallow papillae around spiracular openings; with dense brush of tracheoles issuing from inner end of tracheal chamber.

*Body setae.*—In number and distribution essentially as in second-stage female, though occasionally an extra seta on each segment; all small except on anal segment; typically 8 pairs apparently on head, 19 pairs on thorax, 2 pairs on first abdominal segment, 5 pairs each on second to sixth abdominal segments, inclusive, and 6 pairs each on seventh and anal segments; in all, 66 pairs present.

*Antenna.*—With 4 fleshy setae of varying sizes and a pair of minute setae, not quite wholly invaginated, apparently issuing from a small apical depression.

*Rostralis.*—With one large elongate caudal loop and the characteristic small cephalic loop, when uncoiled within body; in one typical specimen, 2.0 mm long.

*Anal segment.*—Reduced in size; typically 2 pairs of 8-shaped pores on caudal margin; with 6 pairs of setae, all noticeably larger than the other body setae, 3 long slender pairs being on dorsum and 3 stout pairs of varying sizes being on venter. Anal ring apparently present but inconspicuous.

FIGURE 13.—*Palmaricoccus attaleae: A*, Second-stage female, mesothoracic spiracle, × 900; *B*, same, dorsal aspect of posterior end, × 450; *C*, same, mesothoracic spiracular region, × 450; *D*, same, lateral aspect of posterior end, × 150; *E*, adult female, lateral aspect, posterior end, × 650.

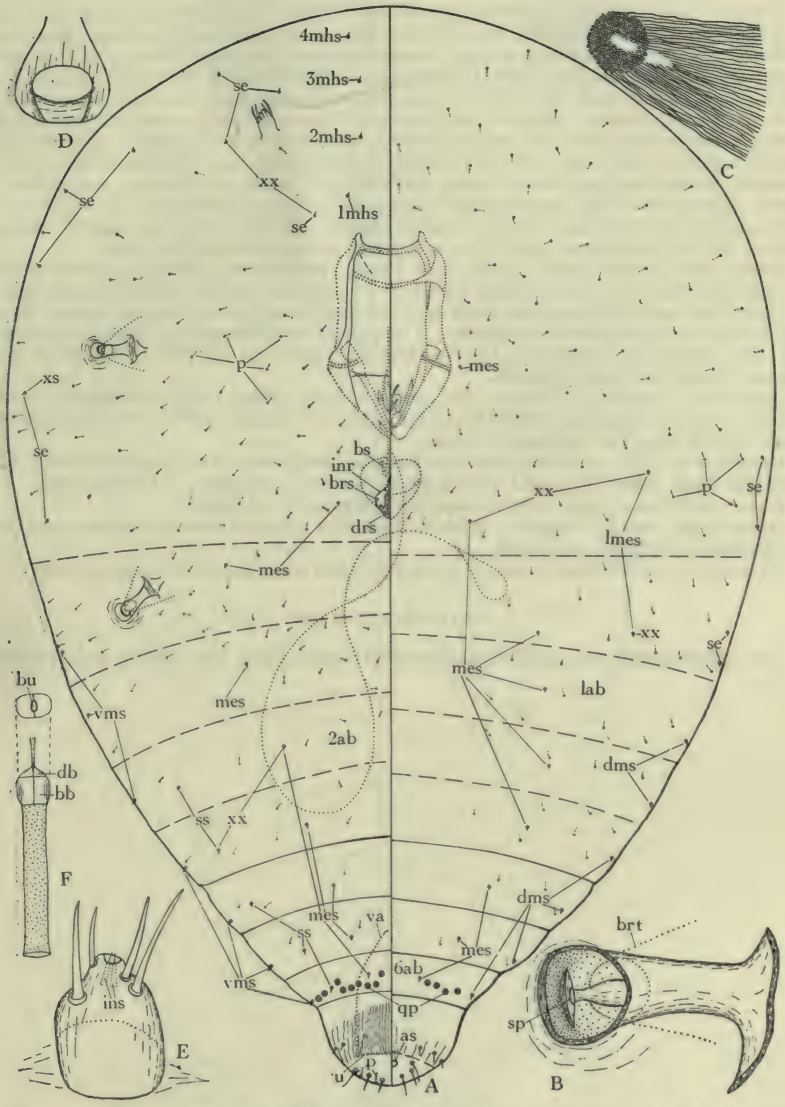


FIGURE 14.—*Palmaricoccus attaleae*, adult female: *A*, Body, dorsal and ventral, × 150; *B*, mesothoracic spiracle, × 900; *C*, brush of tracheoles, × 900; *D*, anal ring, × 1,200; *E*, antenna, × 1,000; *F*, 8-shaped pore, × 3,000.

### SECOND-STAGE MALE

(Figs. 15 and 17, *D*)

*Body.*—Elongate elliptical, with anterior end rounded and posterior end truncated; segmentation obscure except on abdomen; membranous throughout. Papillae absent. A typical specimen 0.40 mm long and 0.18 mm wide.

*Pores.*—8-shaped pores scattered within limits on both surfaces; not numerous; minute; partition extending almost through tube; bars distinguished apart with difficulty; external opening slightly expanded and not surrounded with sclerotic rims; on one side of one typical specimen, 3 dorsal and 5 ventral 8-shaped pores on head, 6 dorsal and 19 ventral ones on prothorax and mesothorax combined, 2 dorsal and 6 ventral ones on metathorax, 2 dorsal ones on first abdominal segment, 1 dorsal one each on second, third, and fourth abdominal segments, 4, 2, and 1 ventral pores on these segments, respectively, and 1 dorsomesal pore on seventh abdominal segment; in all, 54 8-shaped pores present on one side. No pores associated with mesothoracic spiracle, but typically one quinquelocular pore associated with each metathoracic spiracle; this pore may be absent from one side or in its place there may be a trilocular or a quadrilocular pore.

*Body setae.*—Essentially as in first instar except for following setae absent: 4 pairs on head, the lateromesal pairs of dorsum on mesothorax and metathorax, all marginal and submarginal ones on venter of mesothorax posteriorward to and including sixth abdominal segment, 1 marginal or submarginal pair on venter of seventh abdominal segment, the ventromesal pair on anterior section of metathorax; in all, 47 pairs present.

*Antenna.*—Lightly sclerotic and only slightly raised above surface; with 4 minute, stout, spinelike structures, all probably setae, and 2 more or less clear spots which may be vestiges of setae.

*Rostralis.*—With a broad shallow caudal bend and the characteristic small cephalic loop, when uncoiled within body; in one specimen, 0.43 mm long.

*Legs.*—All three pairs in evidence but extremely vestigial.

*Anus.*—On caudal margin, which does not project here; narrow and only moderately sclerotic anal ring.

*Exuviation.*—Old derm pushed back posteriorward into a shapeless mass.

### THIRD-STAGE MALE

No specimens in condition for distinguishing the parts adequately.

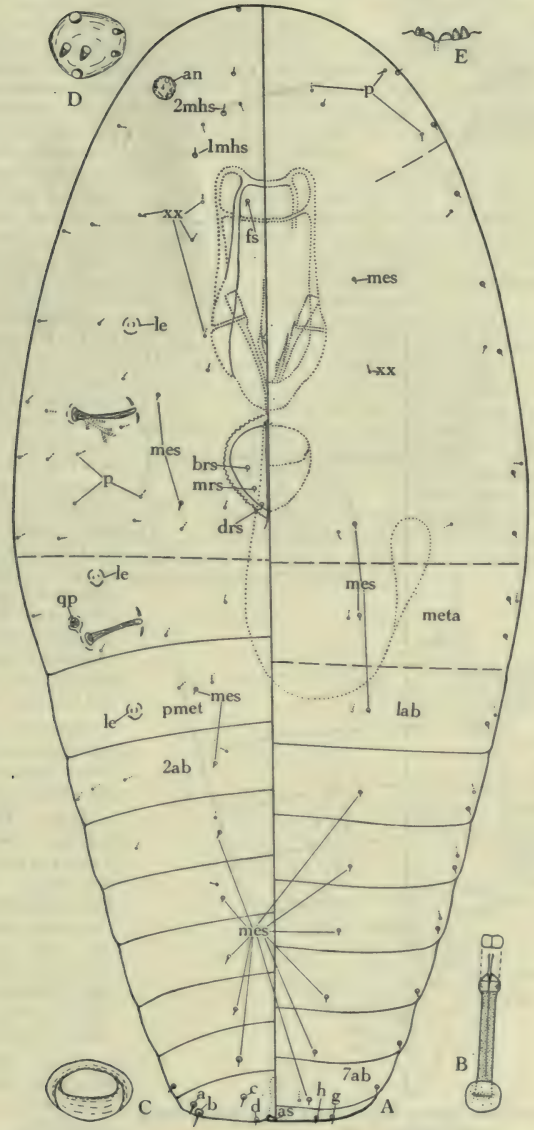


FIGURE 15.—*Palmaricoccus attaleae*, second-stage male: *A*, Body, dorsal and ventral, × 380; *B*, 8-shaped pore, × 3,000; *C*, anal ring, × 2,000; *D*, antenna, × 2,000; *E*, antenna, lateral aspect, × 2,000.

FOURTH-STAGE MALE

(Fig. 16)

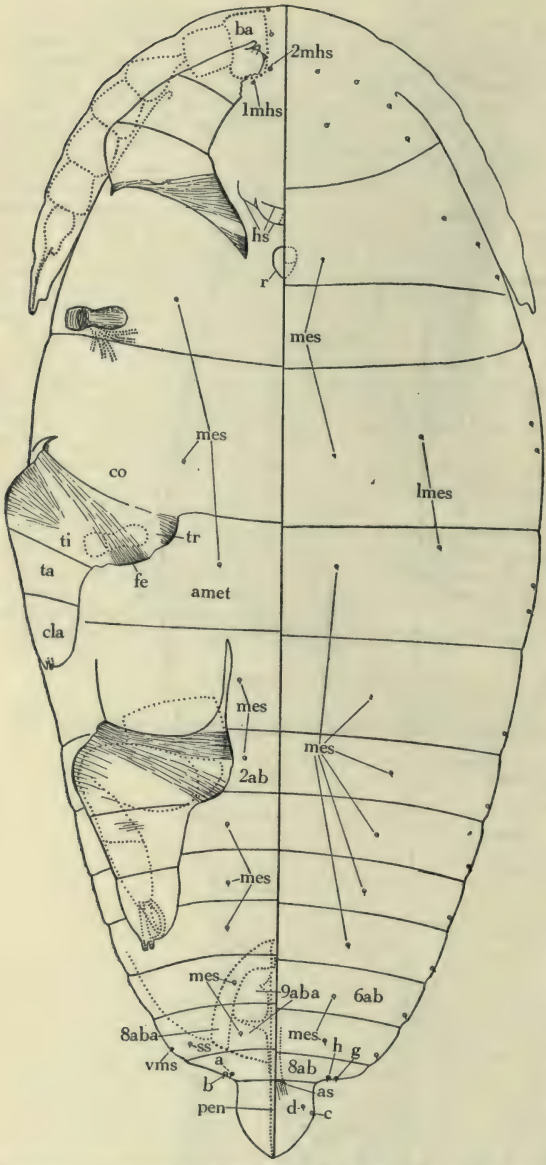


FIGURE 16.—*Palmaricoccus attaleae*, fourth-stage male: Body, dorsal and ventral, × 380.

*Body.*—Moderately elliptical; in outline gently tapering caudad from mesothorax, with posterior projection slightly longer and more pointed than in *Phoenicococcus marlatti;* segmentation of all segments defined except on ventral surface of prothorax and mesothorax. A typical specimen 0.40 mm long and 0.18 mm wide.

*Spiraculariae.*—Stout, cylindrical, strongly sclerotic, subequal.

*Body setae.*—Essentially as in *Phoenicococcus marlatti*, with the following typical exceptions: 3 pairs on head, lateromesal pair of dorsum on prothorax, dorsomesal pair on anterior section of mesothorax, 1 marginal pair on posterior section of mesothorax, a pair immediately caudad of mesothoracic spiracles, and the marginal and submarginal pairs on fourth, fifth, and sixth abdominal segments, all absent; ventromesal pair on second abdominal segment present; in all, 53 pairs present.

*Antenna.*—Slightly more elongate and segmentation less distinct than in *Phoenicococcus marlatti.*

*Legs.*—Broad at base, stocky, and tibiae characteristically sharply elbowed. With more or less sclerotization of trochanter, femur, and tibia. A pair of small, stout, apical projections on each leg, extensions to hold the developing distal tarsal setae of subsequent instar.

*Anal segment.*—Anus distinct, near cephalic margin of ninth abdominal segment.

ADULT MALE

(Fig. 17, *A–C*)

*Body.*—Vestiges of thoracic wing framework and wings absent. Posterior abdominal segment moderately sclerotic. A typical specimen 0.41 mm long and 0.10 mm wide.

*Spiraculariae.*—Stocky, almost barrel-shaped.

*Body setae.*—In distribution essentially as in *Phoenicococcus marlatti*, with the following setae absent: 2 pairs on head, lateromesal pair of dorsum on prothorax, dorsomesal pair on anterior section of mesothorax, 1 marginal and 1 small ventral pair on posterior section of mesothorax, the ventromesal pair of anterior section of metathorax, and 1 marginal or submarginal pair each on fourth, fifth, and sixth abdominal segments; in all, 56 pairs present.

*Antenna.*—Club stocky, with 5 segments appearing to be loosely connected; the 3 middle club segments considerably broader than the other 2 segments; typically with 4 slender setae and 1 fleshy seta on basal segment, 5 slender setae on second, 1 slender seta and 4 fleshy setae on third, 4 slender and 4 fleshy setae on fourth, 5 fleshy setae on fifth, 3 slender and 4 fleshy setae on sixth, and 2 slender and 6 fleshy setae on apical segment; all setae shorter or at most little longer than the segments from which they arise.

*Head skeleton and rostrum.*—A differentiated sclerotic area on ventromeson, possibly a vestige of head skeleton; otherwise no evidence of head skeleton or of rostrum; invagination leading to alimentary tube distinct.

*Legs.*—Metathoracic tibia and tarsus considerably stouter than the other tibiae and tarsi. Each coxa with 5 slender setae of various sizes, besides a minute basal one and 1 moderately long fleshy seta; each trochanter with 2 rather small slender setae, besides a minute basal one; prothoracic femur with 3 slender setae and each of the other 2 femora with 4 slender setae and 1 fleshy seta; prothoracic and mesothoracic tibiae each with 3 slender and 2 fleshy setae; metathoracic tibia with 5 slender and 2 fleshy setae; prothoracic tarsus with 4 slender setae and 1 fleshy seta; mesothoracic tarsus with 4 slender and 2 fleshy setae and metathoracic tarsus with 4 slender and 5 fleshy setae; each claw with 2 setae, 1 apparently fleshy and the other slender.

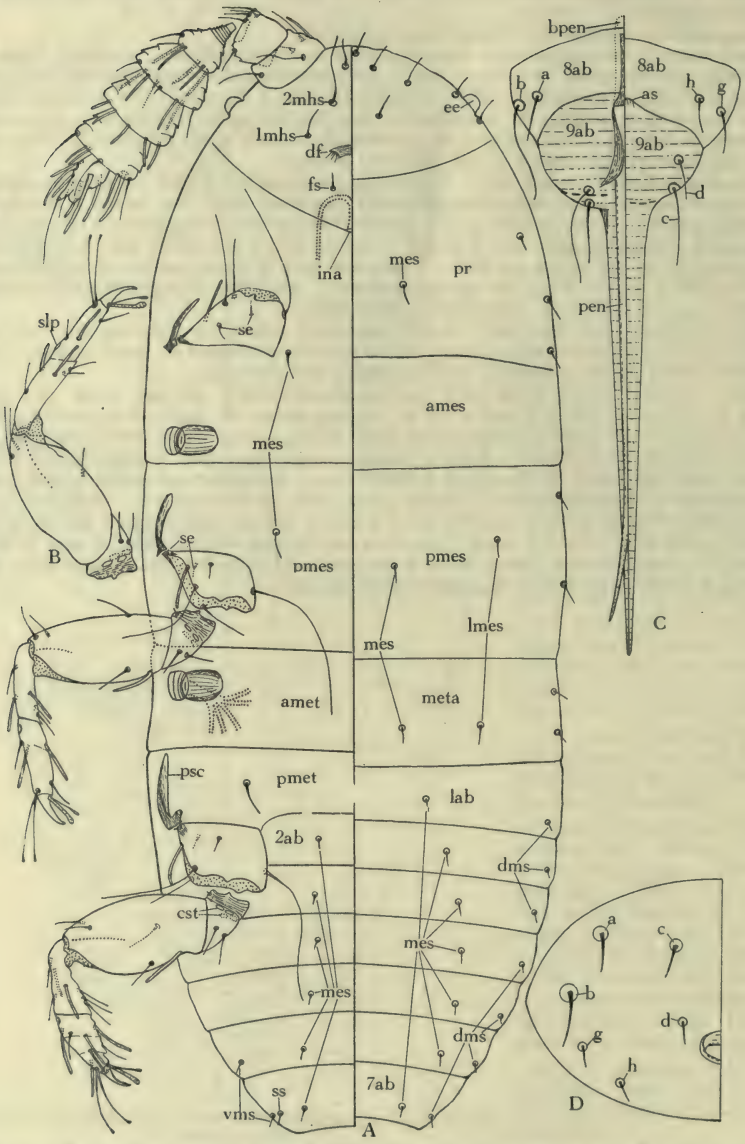


FIGURE 17.—*Palmaricoccus attaleae: A*, Adult male, body, dorsal and ventral, × 450; *B*, same, prothoracic leg, dorsum, × 450; *C*, same, posterior end, dorsal and ventral, × 900; *D*, second-stage male, anal segment, × 900.

PALMARICOCCUS PRITCHARDIAE, new species

Material from E. M. Ehrhorn. Two lots: One collected by J. F. Rock in 1919 on fruit of *Pritchardia hardyi* at 3,000-foot elevation, Molokai Island, Hawaii; the other collected by O. H. Swezey in 1916 on fruit of *Pritchardia rockiana* at Punaluu, Oahu, Hawaii.

EGG

(Fig. 18, *E*)

Oviparous. Spine strongly sclerotic.

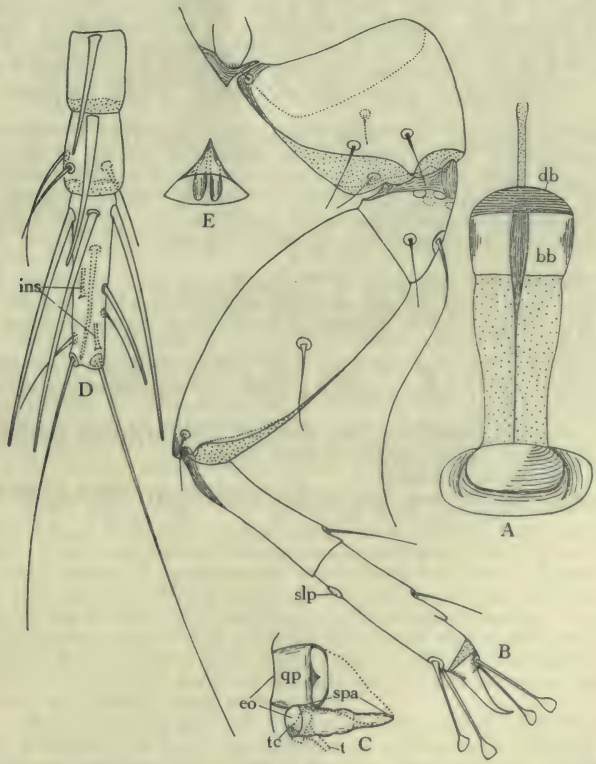


FIGURE 18.—*Palmaricoccus pritchardiae: A*, First-stage nymph, caudodorsal pore, × 3,000; *B*, same, metathoracic leg, × 1,000; *C*, same, mesothoracic spiracle, × 1,200; *D*, same, antenna, apical part, × 1,000; *E*, egg spine, × 1,500.

FIRST STAGE

(Fig. 18, *A–D*)

*Body.*—Elongate elliptical. Usually with a distinctly sclerotic area laterocephalad of head skeleton. A distinct furca on meson between mesothoracic and metathoracic segments. Two posterior abdominal segments more sclerotic than other body segments. Typical newly hatched specimen 0.36 mm long and 0.16 mm wide; fully developed female specimen 0.46 mm long and 0.28 mm wide; fully developed male specimen 0.39 mm long and 0.21 mm wide. Male instar not puparial, its derm not strongly sclerotic.

*Pores.*—8-shaped pores larger than, but in structural details essentially as, in *Palmaricoccus attaleae.* In distribution 8-shaped pores typically as follows: 2 pairs on or near dorsal margin of head, 1 pair cephalad of eyes and the other caudad of eyes; 4 dorsomesal pairs in a row on thorax; 1 dorsomarginal pair each on sixth and eighth abdominal segments; 1 ventromarginal pair near each spiracle and on each of second to fifth abdominal segments, inclusive; in all, 14 pairs present. A single quinquelocular pore associated with each of four spiracles.

*Spiracles.*—Spiracullariae approximately alike, small, elongate, strongly sclerotic.

*Body setae.*—Nearly as in *Palmaricoccus attaleae,* with the following most noticeable variations: Third ventromesal head pair almost as large as second ventromesal head pair; the small ventromesal pair of anterior section of metathorax and the dorsomesal pair of seventh abdominal segment absent; dorsomesal pairs approximately same size as marginal pairs; in all, 67 pairs present. In one specimen, outer and inner long caudal pairs, respectively, 67 and 187 microns long.

*Antenna.*—Essentially like that of *Palmaricoccus attaleae* except larger, with the minute seta near inner margin of third segment possibly absent, and a large fleshy seta present on fourth segment; resembling *Phoenicococcus marlatti* in these two particulars.

*Rostralis.*—With 1 long caudal loop and 1 or 2 roundish caudal loops, when uncoiled within body; length more like that of *Phoenicococcus marlatti;* in one specimen, 1.10 mm long.

*Legs.*—In structure essentially like those of *Palmaricoccus attaleae* except for presence of a seta on inner margin of each tibia.

*Exuviation.*—No data available.

*Dried material.*—In crevices; light brown; moderately well covered with matted filaments.

### SECOND-STAGE FEMALE

(Fig. 19, *A–E*)

*Body.*—More or less pyriform, especially in older individuals; segmentation obscure except for the 4 or 5 posterior abdominal segments; in younger individuals derm membranous except seventh abdominal segment and anal valve, which are distinctly sclerotic; sclerotization spreading cephalad, but in decreasing degree, to and including fourth abdominal segment, before general thickening of derm takes place. Stout, spinelike, but not typically curved, papillae thickly covering both surfaces; comparatively large marginally, decreasing in size mesad, more rapidly on ventral than on dorsal surface; fully developed specimens heavily sclerotic, obscuring papillae. In older specimens, with a membranous area on each side of head skeleton for penetration of adult rostralis; less circular and more caudad in position than that of *Palmaricoccus attaleae.* A typical newly molted specimen 0.64 mm long and 0.33 mm wide; a rather small puparium 1.3 mm long and 0.7 mm wide; a rather large puparium 1.65 mm long and 0.85 mm wide.

*Pores.*—8-shaped pores scattered over both surfaces; numerous, most abundant along cephalic and lateral margins and submargins, particularly on ventral surface; stouter in general than those in *Palmaricoccus attaleae,* marginal ones largest, dorsomesal ones of abdomen smallest; partitions extending through tubes nearly to their external openings; bars can be distinguished apart; bullae delicate; number on one side of each of following segments or combination of segments of a single specimen approximately as follows: Head, 40 ventral, 19 dorsal; prothorax and anterior section of mesothorax together, 55 ventral, 26 dorsal; posterior section of mesothorax, 40 ventral, 18 dorsal; metathorax and first abdominal segment together, 65 ventral, 30 dorsal; second and third abdominal segments each, 25 ventral, 12 dorsal; fourth abdominal segment, 12 ventral, 9 dorsal; sixth abdominal segment, 1 ventral, none dorsal; fifth and seventh abdominal segments, none on either surface; on one side of one typical specimen, in all, 263 on venter and 126 on dorsum, thus approximately twice as many on ventral as on dorsal surface, and altogether three and a half times as many as in *Palmaricoccus attaleae.* A rather compact group of quinquelocular pores associated with each of 4 spiracles; in a count of 40 groups of quinquelocular pores, 20 associated with mesothoracic and 20 with metathoracic spiracles, the range in number in each group being 14 to 54 and 12 to 56, and the average number 37.6 and 34.8, for the mesothoracic and metathoracic spiracles, respectively.

*Spiracles.*—Both pairs and their accompanying quinquelocular pores open practically on surface, with no surrounding distinct sclerotic thickenings or plates.

*Body setae.*—Essentially as in *Palmaricoccus attaleae,* with typically the following 13 additional setae: 1 ventromesal pair laterad of head skeleton; 1 dorsosubmarginal pair each on first to sixth abdominal segments, inclusive; 1 ventromesal pair each on fourth, fifth, and sixth abdominal segments; 3 pairs on anal valve; in all, 11 pairs on head, 12 pairs on prothorax and mesothorax together, 7 pairs on metathorax, 3 pairs on first, 6 pairs each on second and third, 7 pairs each on fourth, fifth, and sixth, 5 pairs on seventh abdominal segment, and 6 pairs on anal valve, or a total of 77 pairs present.

*Antenna.*—More elongate than in *Palmaricoccus attaleae;* with a raised, membranous base and sclerotic distal part lacking a sunken area; with 5 fleshy setae varying in size and position, and 2 small, slender, almost wholly evaginated setae, which are considered to be homologous with the pair of invaginated setae of *Palmaricoccus attaleae;* all setae arising from distal part of antenna.

*Rostralis.*—In one typical specimen, 2.2 mm long.

*Anal valve.*—Covered with sclerotic tissue, which in younger specimens is usually marked with irregular lines and numerous spinelike thickenings; in older specimens tissue heavy, obscuring markings; with 6 pairs of setae, 2 cephalolateral pairs being slightly larger than the others. Anus cephalad in position; anal ring apparently present but insignificant.

*Dried material.*—Puparium more frequently observed wedged beneath calyces of fruit; dark reddish brown; much matted wax scattered over body; varying in size and form; dorsum more convex than in *Palmaricoccus attaleae,* but body never globular; margins rounded; posterior end pointed dorsocaudad.

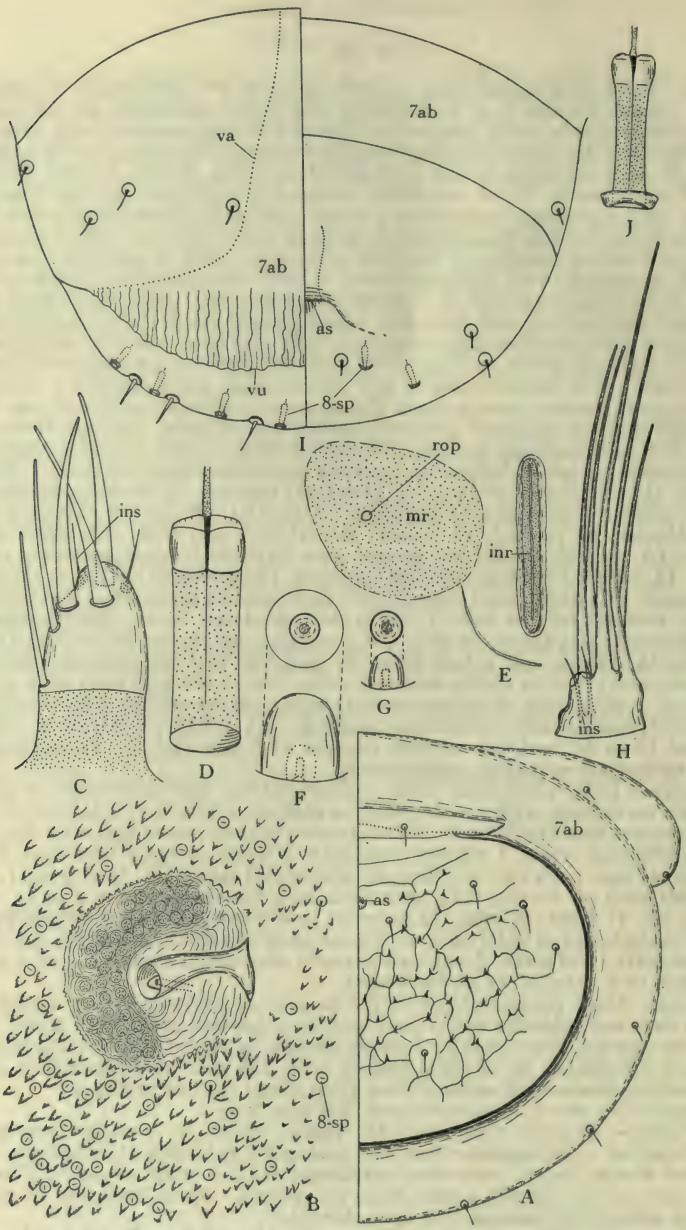


FIGURE 19.—*Palmaricoccus pritchardiae*: *A*, Second-stage female, posterior end, dorsal surface, × 500; *B*, same, mesothoracic spiracle, × 500; *C*, same, antenna, × 1,000; *D*, same, 8-shaped pore, × 3,000; *E*, same, midventral region of puparium, × 160; *F*, *G*, third-stage female, large and small derm tubercles, × 1,500; *H*, adult female, antenna, × 1,000; *I*, same, posterior end, dorsal and ventral, × 500; *J*, same, 8-shaped pore, × 3,000.

### THIRD-STAGE FEMALE

(Fig. 19, *F* and *G*)

Pyriform; derm membranous but firm; many rounded tuberculate structures of varying sizes scattered over both surfaces, possibly thickenings around pores of preceding instar; spiracles similar to those in *Palmaricoccus attaleae;* with two clear areas where one would normally expect to find antennae.

### ADULT FEMALE

(Fig. 19, *H–J*)

*Body.*—Moderately elliptical to pyriform; posterior end drawn out a little more than in *Palmaricoccus attaleae;* segmentation obscure except on both surfaces of the five posterior segments; derm membranous except for faint sclerotization of caudal part of anal segment; papillae very small and numerous around spiracles and ventromesal surface of thorax. Typical specimen 1.1 mm long and 0.74 mm wide.

*Pores.*—8-shaped pores distributed over ventral surface of all segments of body with possible exception of sixth and seventh abdominal ones; considerably concentrated on this surface about midway between lateral margins and meson; apparently absent on dorsum; in structure essentially as in second-stage female except external openings surrounded by sclerotic rims. On one side of typical specimen, the following number of 8-shaped pores: 67 from cephalic margin of head to, but not including, posterior section of mesothorax; 53 on next two segments, practically embracing the area between lines drawn through caudal margins of spiracles; 20, 16, 12, 6, and 2 on the segments immediately following, in consecutive order; in all, 176 counted on one side; with a moderate variation in their number on the different segments, especially on thorax. Quinquelocular and other types of pores absent.

*Spiracles.*—A moderate number, not a brush, of tracheoles, issuing from inner end of each tracheal chamber.

*Body setae.*—Distributed essentially as in second-stage female except typically 1 more pair on head, 5 more pairs on thorax, and 1 more pair on third abdominal segment; in all, 12 pairs on head, 16 pairs on prothorax and mesothorax together, 8 pairs on metathorax, 3 pairs on first, 6 pairs on second, 7 pairs each on third to sixth abdominal segments, inclusive, 5 pairs on seventh abdominal segment, and 6 pairs on anal segment; in all, 84 pairs present.

*Antenna.*—With five long fleshy setae of varying sizes and a pair of small setae, which are only partially invaginated.

*Rostralis.*—With 1 elongate loop, 2 large roundish loops, and the small cephalic loop, when uncoiled within body; in one typical specimen, 3.8 mm long.

*Anal segment.*—Somewhat less reduced in size than in *Palmaricoccus attaleae;* with typically 6 pairs of 8-shaped pores, 2 pairs distinctly on dorsal surface and 4 pairs along caudal margin; 6 pairs of setae, 3 pairs approximately the size of the other body setae on dorsum and the remaining 3 pairs stout; anal ring obscure, if not absent.

SECOND-STAGE MALE

(Fig. 20)

*Body.*—Moderately elliptical, with both ends about equally rounded; segmentation distinct except on ventral surface of head, prothorax, and mesothorax; in younger individuals lightly sclerotic, with increasing sclerotization posteriorward on the four posterior abdominal segments, which in older individuals are likewise sclerotic, though remainder of body appears to become more or less membranous. Papillae small and spinelike; numerous marginally and submarginally on both surfaces, gradually disappearing mesally on both surfaces, but here numerous irregular rows of spiny and serrated spicules occur. A typical newly molted specimen 0.36 mm long and 0.20 mm wide; a fully developed specimen 0.44 mm long and 0.21 mm wide.

*Pores.*—8-shaped pores fairly numerous; scattered over both surfaces of body; subequal[1] in size; in structure essentially as in *Palmaricoccus attaleae* except slightly larger and external openings surrounded with narrow sclerotic rims; on one side of one typical specimen were: 18 on head, 54 on thorax, 6 on first, 16 on second, 14 on third, 15 on fourth, 14 on fifth, 16 on sixth, and 10 on seventh abdominal, and 13 on anal segment, or 104 on abdomen; in all, 176 on one side of body. Typically from 4 to 8 quinquelocular pores associated with each mesothoracic and 1 to 3 with each metathoracic spiracle; all rather closely grouped about each spiracle.

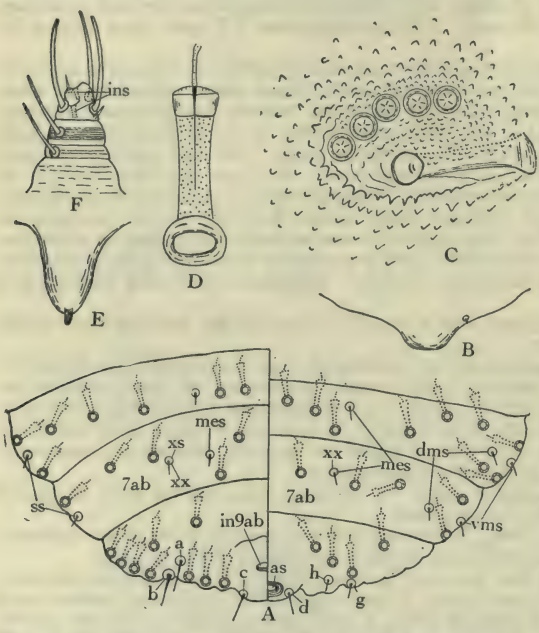


FIGURE 20.—*Palmaricoccus pritchardiae*, second-stage male: *A*, Posterior end, dorsal and ventral, × 500; *B*, metathoracic leg, × 1,500; *C*, mesothoracic spiracle, × 1,000; *D*, lateromarginal 8-shaped pore, × 3,000; *E*, another metathoracic leg, × 1,500; *F*, antenna, × 1,000.

*Body setae.*—Essentially as in *Phoenicococcus marlatti*, with the following exceptions: 2 less pairs on or near margin of head, the lateromesal pairs of dorsum on prothorax and anterior section of mesothorax absent, 1 ventromesal pair present on second abdominal and 1 extra pair, considered to belong to the ventromesal series, on seventh abdominal segment, 1 less pair on anal segment; thus in all, 75 pairs present.

*Antenna.*—Rather elongate; apparently composed of 4 segments; with 5 large fleshy setae and apparently 2 minute spinelike ones, besides the small invaginated pair.

*Rostralis.*—With 1 elongate loop, 2 broad rather deep loops, and the characteristic small cephalic loop, when uncoiled within body; in one typical specimen, 0.93 mm long.

*Legs.*—May or may not be evident; usually vestigial in character.

*Anus.*—On or near caudal margin, which projects slightly here; anal ring rather broad and strongly sclerotic.

*Exuviation.*—No data available.

THIRD, FOURTH, AND ADULT MALE STAGES

Not available.

PALMARICOCCUS NESIOTES (Laing) (*10*)

Material from Frederick Laing, on "palm sp.", Lord Howe Island, South Pacific Ocean; E. E. Green, same source; United States Bureau of Entomology (Kotinsky no. 134), "on palm", Macheno, Hawaii, August 24, 1906. All along depressions of pinnae.

EGG

Not identified.

FIRST STAGE

(Fig. 21)

*Body.*—Moderately elliptical. Usually with a distinctly sclerotic area cephalad of head skeleton. Thoracic furcae obscure. Posterior abdominal segment typically more or less sclerotic. Dorsal surface of abdomen becoming clearly sclerotic and sharply delimited in fully developed female specimens, but not in the male. Typical newly hatched specimen 0.22 mm long and 0.13 mm wide; fully developed specimen of either sex about 0.29 mm long and 0.20 mm wide. Male instar not puparial.

*Pores.*—8-shaped pores occurring typically as follows: 2 large dorsomarginal pairs on head, 1 cephalad and 1 caudad of eyes; 5 small dorsomesal pairs in a row on thorax and second abdominal segment together; 1 small dorsosubmarginal pair each on mesothorax and first and seventh abdominal segments; 1 large dorsomarginal pair on eighth abdominal segment; 1 large ventromarginal pair laterad of each spiracle, and on each of second, fourth, and sixth abdominal segments; in all, 16 pairs present. A single quinquelocular pore associated with each mesothoracic spiracle.

*Spiracles.*—Spiracullariae elongate, distinctly sclerotic.

*Body setae.*—In distribution about as in *Palmaricoccus attaleae*, with the following exceptions: Frontal pair on head absent, the small ventromarginal pair and the more mesal pair caudad of mesothoracic coxa on anterior section of metathorax apparently always absent; ventromesal pair not observed on second abdominal segment; in all, 65 pairs present. In one specimen, outer and inner long caudal pairs, respectively, 29 and 101 microns long.

*Antenna.*—Much like that in *Palmaricoccus pritchardiae*, though much smaller.

*Rostralis.*—With a single long caudal loop besides the characteristic small cephalic loop, when uncoiled within body; in two specimens, 0.44 and 0.47 mm long, respectively.

*Legs.*—About as in *Palmaricoccus attaleae*, except for presence of a single seta on femur and none on tibia.

*Exuviation.*—In male, the break occurring caudad of antennae and eyes, the ventral skin, with head skeleton and rostrum not in an inverted position, being pushed toward posterior end, leaving a dorsal shell; in female, anterior half of dorsal surface appearing to break irregularly, the ventral derm of anterior half, including antennae, folding over onto posterior half of body, thus placing antennae near anus, with head skeleton and rostrum in an inverted position.

*Dried material.*—Bright reddish brown at first, old specimens darker brown; moderately well covered with whitish matted filaments.

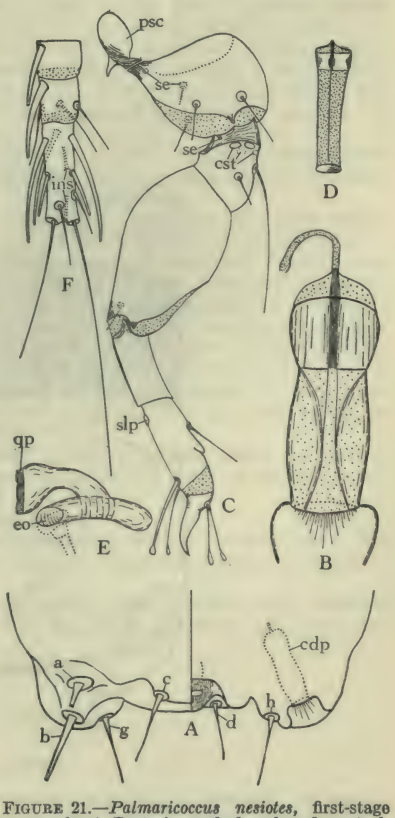


FIGURE 21.—*Palmaricoccus nesiotes*, first-stage nymph: *A*, Posterior end, dorsal and ventral, × 1,200; *B*, dorsal 8-shaped pore, × 3,000; *C*, metathoracic leg, × 1,000; *D*, dorsomesal 8-shaped pore, × 3,000; *E*, mesothoracic spiracle, × 2,000; *F*, antenna, apical part, × 1,000.

SECOND-STAGE FEMALE

(Fig. 22)

*Body.*—Moderately elliptical; seventh abdominal segment characteristically projecting caudally; segmentation distinct on venter of abdomen, elsewhere

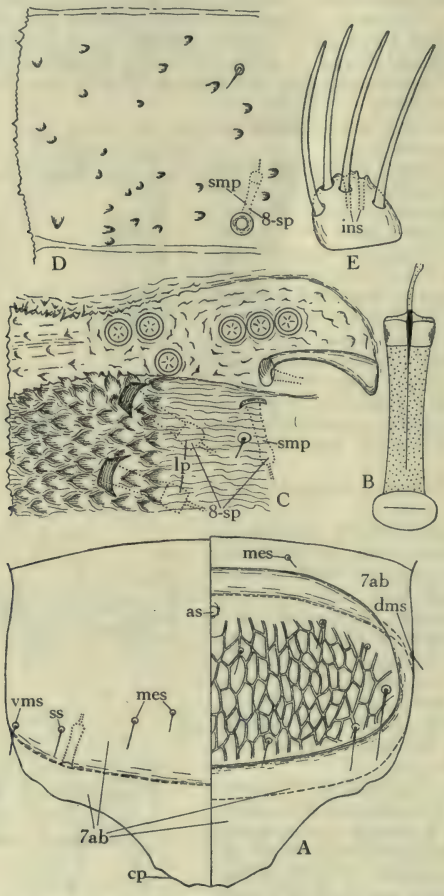


FIGURE 22.—*Palmaricoccus nesiotes*, second-stage female: *A*, Posterior end, dorsal and ventral, × 500; *B*, 8-shaped pore, × 3,000; *C*, mesothoracic spiracle, × 1,000; *D*, dorsolateral surface, second abdominal segment, × 1,000; *E*, antenna, × 1,000.

obscure; membranous except for possibly a narrow border of seventh abdominal segment immediately around anal valve, and for anal valve, which is moderately sclerotic in its entirety; sclerotization increasing little, if any, cephalad of here before general thickening of derm takes place preceding puparial state. Entire ventral margin thickly covered with stout papillae, rather acutely pointed, uniformly arranged, and restricted to a moderately narrow band around this margin, but the ventromesal region of thorax and abdomen with numerous rows of small spicules; on dorsum a number of small blunt papillae extending to meson. Membranous areas laterad of head skeleton not distinguished, rostralis of adult apparently being forced through the more or less undifferentiated derm. Puparium but moderately sclerotic on dorsum, less so on venter. A newly molted specimen 0.37 mm long and 0.19 mm wide; a typical puparium 0.74 mm long and 0.36 mm wide.

*Pores.*—8-shaped pores situated largely along margin and submargin of both surfaces of thorax and abdomen, with a few scattered elsewhere; of two different sizes; partitions extending nearly to external openings; bars can be distinguished apart. The distinctly larger 8-shaped pores situated typically as follows: 4 to 6 pairs each on ventral margin of head, prothorax, and anterior section of mesothorax together, and posterior section of mesothorax; 2 or 3 pairs on each section of metathorax and each abdominal segment to and including the sixth; 1 pair on seventh abdominal segment. The smaller 8-shaped pores situated typically as follows: Submarginally and mesally on ventral surface, 8 to 10 pairs on prothorax and mesothorax together, and 2 or 3 pairs on metathorax and on each abdominal segment except seventh; marginally and submarginally on dorsal surface, 4 pairs on head, 6 pairs on prothorax, and 1 to 3 pairs on each remaining body segment except anal valve; mesally on dorsal surface, 1 pair on each body segment except sixth and seventh abdominal ones and anal valve. In one typical specimen, 56 pairs of 8-shaped pores of both sizes on venter and 36 pairs on dorsum; along ventrosubmargin the two sizes almost intermingling. Typically 4 to 6 quinquelocular pores associated with each mesothoracic and a single pore with each metathoracic spiracle; mesothoracic pores in shallow depressions leading to spiracles and not closely bunched.

*Spiracles.*—Mesothoracic but not metathoracic pair in shallow depressions reaching to body margin; with no surrounding distinct sclerotic plates; spiraculariae quite slender.

*Body setae.*—Essentially as in *Palmaricoccus attaleae*, with the following variations: 1 less pair on head; 2 additional pairs on posterior section of mesothorax, 1 caudad of mesothoracic spiracles and the other laterad of rostrum; 2 additional pairs on posterior section of metathorax and first abdominal segment together, these near ventral margin; 1 additional pair each near ventral margin of second to seventh abdominal segments, inclusive, but apparently no ventral mesal pair on second abdominal segment; 3 additional pairs on anal valve; thus typically 10 pairs on head, 13 pairs on prothorax and mesothorax together, 9 pairs on metathorax, 2 pairs on first abdominal segment, 5 pairs on second, 6 pairs each on third to seventh abdominal segments, inclusive, and 6 pairs on anal valve, or a total of 75 pairs present.

*Antenna.*—Restricted to a single distinctly sclerotic apical piece without a sunken area; with typically 4 fleshy subequal setae and a pair of small wholly invaginated setae.

*Rostralis.*—In one typical specimen, 1.44 mm long.

*Anal valve.*—Covering tissue reticulate in appearance with 6 pairs of setae, the 2 most lateral pairs somewhat larger than the others. Anus situated near cephalic border; anal ring apparently absent.

*Dried material.*—Puparium bright to dark brown; well covered with matted filaments; moderately flattened, with rounded margins; posterior end pointed dorsocaudad.

THIRD-STAGE FEMALE

Not identified.

ADULT FEMALE

(Fig. 23)

*Body.*—Elongate elliptical, with moderate slope toward posterior end, which projects less roundly than in *Palmaricoccus attaleae* and *P. pritchardiae*, and has a characteristic wavy margin; segmentation distinct on ventral surface of thorax and abdomen, and on dorsum of the three posterior abdominal segments; membranous except for moderate sclerotization of caudodorsal part of anal segment. Papillae absent except for some prominent ones and some others small, all more or less spinelike, grouped with spicules and ridges in irregular rows about each spiracle. A typical specimen 0.67 mm long and 0.30 mm wide.

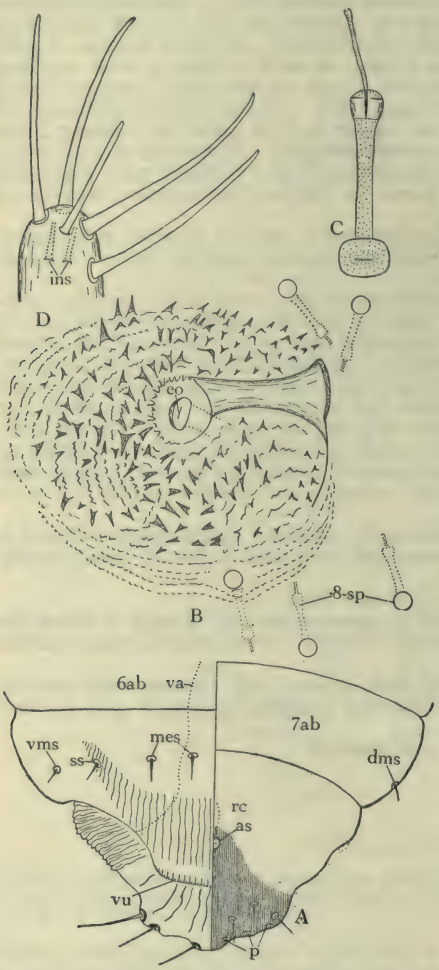


FIGURE 23.—*Palmaricoccus nesiotes*, adult female: *A*, Posterior end, dorsal and ventral, × 500; *B*, mesothoracic spiracle, × 1,000; *C*, 8-shaped pore, × 3,000; *D*, antenna, × 1,000.

*Pores.*—Not numerous; typically located in submarginal and mesal regions of ventral surface of thorax and abdomen, except on anal segment; partitions apparently no more than through bars; bars can be distinguished apart; bullae elongate; external openings somewhat expanded and not surrounded by sclerotic rims; typically no pores on head, 11 or 12 scattered pairs in the general region around each mesothoracic spiracle and between latter and head skeleton, 5 or 6 scattered pairs around each metathoracic spiracle, none to 3 pairs on each abdominal segment; in one typical specimen 29 pairs counted. Quinquelocular pores absent.

*Spiracles.*—With a moderate number of tracheoles issuing from tracheal chamber.

*Body setae.*—More limited in distribution than in second-stage female; apparently absent submarginally and mesally on dorsum, except on the 5 posterior abdominal segments. Typically 7 scattered pairs on head, 19 pairs on thorax, 1 pair on first, 3 pairs each on second and third, 5 pairs on fourth, 6 pairs each on fifth and sixth, and 5 pairs on seventh abdominal segment, and 6 pairs on anal segment; in all, 61 pairs present.

*Antennae.*—With five fleshy setae and pair of small setae, which are wholly invaginated.

*Rostralis.*—With one elongate loop and the small cephalic loop, when uncoiled within body; in one typical specimen, 2.2 mm long.

*Anal segment.*—Less reduced in size than in *Palmaricoccus attaleae;* typically with 3 pairs of 8-shaped pores along caudal margin; with 6 pairs of setae, 3 pairs being on dorsum and of approximately the same size as the other body setae, and 3 prominent pairs along caudal margin, long and somewhat stout; anal ring, if present, inconspicuous.

SECOND-STAGE MALE

(Fig. 24)

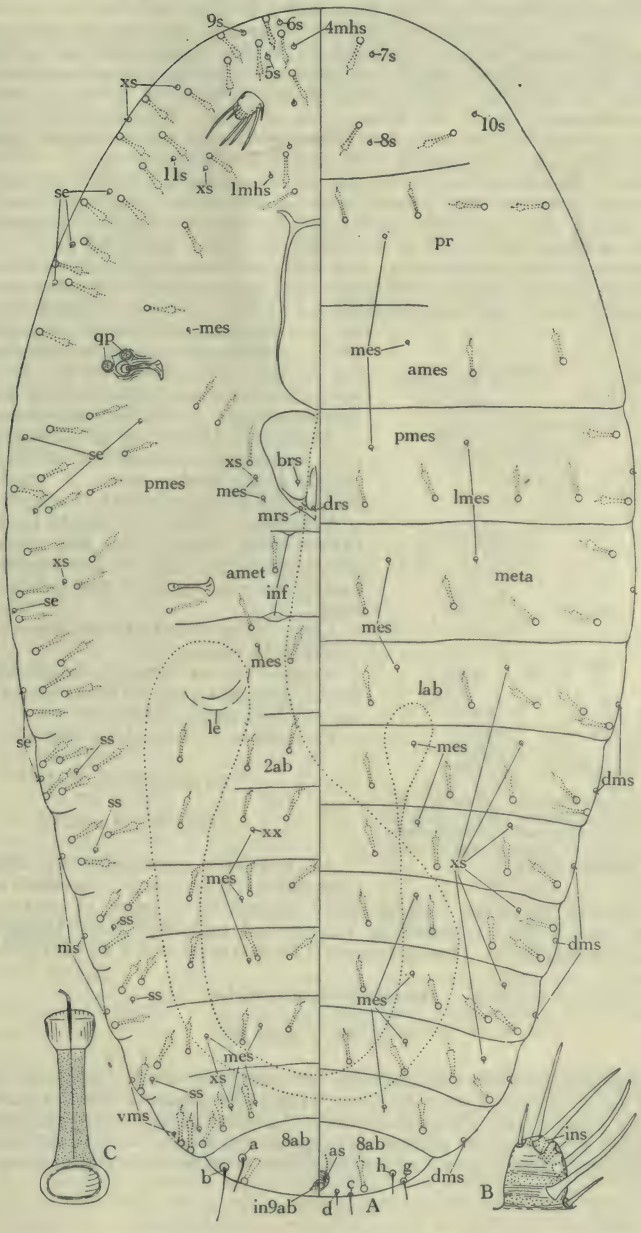


FIGURE 24.—*Palmaricoccus nesiotes*, second-stage male: *A*, Body, dorsal and ventral, × 500; *B*, antenna, × 1,000; *C*, 8-shaped pore, × 3,000.

*Body.*—Moderately elliptical, with both ends about equally rounded; segmentation distinct except on ventral surface of head, prothorax, and mesothorax; in younger specimens very lightly sclerotic, with increasing sclerotization posteriorward on the four posterior abdominal segments, which in older specimens are like-

wise sclerotic, though remainder of body appears to be membranous. Papillae small, spinelike, numerous marginally and submarginally, but rapidly disappearing mesad, where numerous irregular rows of spiny and serrated spicules occur on ventral surface. A newly molted specimen 0.29 mm long and 0.17 mm wide; a fully developed specimen 0.46 mm long and 0.21 mm wide.

*Pores.*—8-shaped pores fairly numerous; scattered generally over both surfaces; slightly smaller mesad on both surfaces; in structure essentially as in *Palmaricoccus attaleae* except slightly larger and external opening surrounded by a narrow sclerotic rim; on one side of one typical specimen were: 16 on head, 50 on thorax, and 66 on abdomen; in all, 132 on one side of body. Typically 2 to 3 but sometimes only 1 quinquelocular pore associated with each mesothoracic spiracle, and 1 or, more often, none associated with metathoracic spiracles.

*Body setae.*—Essentially as in *Phoenicococcus marlatti*, with the following exceptions: Frontal pair on head absent and second ventromesal pair on head not distinctly larger than adjacent pairs; the lateromesal pairs of dorsum on prothorax and anterior section of mesothorax absent; 1 marginal pair absent from mesothorax and from metathorax, and the ventromesal pair on anterior section of metathorax absent, but an additional ventromesal pair on posterior section of mesothorax; 1 extra pair each, considered as belonging to "lateromesal" series, on first to sixth abdominal segments, inclusive; 1 extra pair each, considered as belonging to the ventromesal series, on sixth and seventh abdominal segments; 1 less pair on anal segment; in all, 80 pairs present.

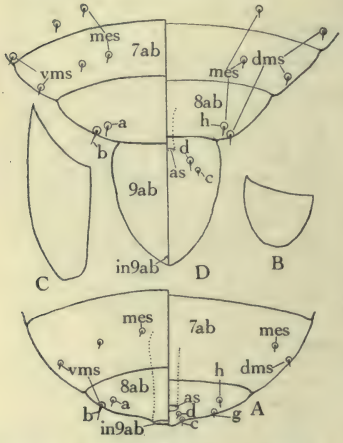


FIGURE 25.—*Palmaricoccus nesiotes: A*, Third-stage male, posterior end, dorsal and ventral; *B*, same, wing pad; *C*, fourth-stage male, wing pad; *D*, same, posterior end, dorsal and ventral. × 400.

*Antenna.*—Occurring as a rounded tubercle; apparently composed of 3 segments; with 4 large fleshy setae, 2 smaller fleshy setae, and a pair of small invaginated setae.

*Rostralis.*—With 1 elongate loop, 2 broad rather deep loops, and the characteristic small cephalic loop, when uncoiled within body; in one typical specimen, 1.03 mm long.

*Legs.*—Not always in evidence; when so, vestigial in character.

*Anus.*—On or near dorsocaudal margin, which does not project here; anal ring rather narrow but well sclerotized.

*Exuviation.*—No data available.

### THIRD-STAGE MALE

(Fig. 25, *A* and *B*)

All available specimens too delicate for adequate study; short rounded wing pads present; delicate setae on various body segments; 5 pairs of setae on eighth abdominal, and 6 pairs, including 1 marginal pair distinctly larger than the others, on anal segment. One specimen 0.39 mm long and 0.20 mm wide.

### FOURTH-STAGE MALE

(Fig. 25, *C* and *D*)

All available specimens too delicate for adequate study; posterior projection essentially as in *Palmaricoccus attaleae;* wing pads present, distinctly longer than in preceding instar; with delicate setae on the various segments, including 5 pairs each on sixth and seventh abdominal segments, 4 pairs on eighth, and 2 pairs on anal segment; legs sharply elbowed. One specimen 0.41 mm long and 0.20 mm wide.

### ADULT MALE

(Fig. 26)

*Body.*—Vestiges of thoracic wing framework may be indicated by pronounced depressions along cephalic and caudal borders of dorsal surface of mesothorax.

Anal segment only segment clearly sclerotic. A typical specimen 0.51 mm long and 0.18 mm wide.

*Spiraculariae.*—Elongate, with lateral ends somewhat expanded; strongly sclerotic, subequal.

*Body setae.*—Available material not in condition for full determination, but at least as fully represented as in *Palmaricoccus attaleae.*

*Antenna.*—Club elongate, with seven segments, all closely joined. Typically 3 slender setae on basal segment, 2 slender setae on second, 1 slender and 6 fleshy setae on third, 3 slender and 5 fleshy setae each on fourth and fifth, 4 slender and 8 fleshy setae on sixth, 3 or 4 slender and 6 fleshy setae on seventh and eighth, and 1 slender and 6 fleshy setae, besides a pair of minute at least partially evaginated setae on apical segment; setae of club large, nearly all longer and many considerably longer than the segments from which they arise.

*Head skeleton and rostrum.*—Vestiges of head skeleton and rostrum distinct; invagination leading to alimentary tube in evidence.

*Legs.*—The three pairs subequal. The setae of a metathoracic leg occur typically as follows: Coxa 4 slender and 4 fleshy setae besides the minute basal one, trochanter 1 slender and 2 fleshy setae, femur 4 slender and 5 fleshy setae, tibia 8 slender and 8 fleshy setae, tarsus 4 slender and 12 fleshy setae, claw 2 setae. Slender setae of various sizes, mostly rather small; fleshy setae large. Setae on the other 2 pairs of legs approximately as on metathoracic legs.

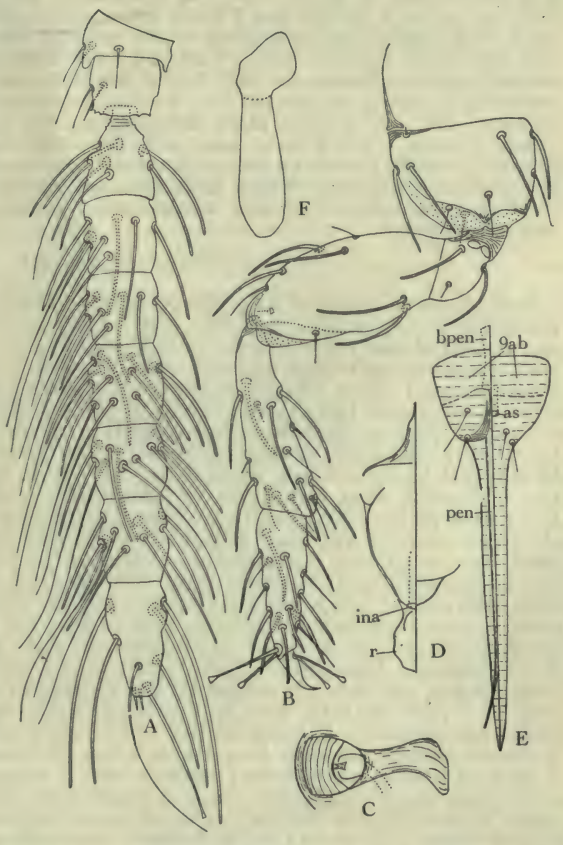


FIGURE 26.—*Palmaricoccus nesiotes*, adult male: *A*, Antenna, × 400; *B*, metathoracic leg, × 400; *C*, mesothoracic spiracle, × 1,000; *D*, head skeleton, dorsal and ventral, × 400; *E*, posterior end, dorsal and ventral, × 400; *F*, wing pad, × 400.

**Genus HALIMOCOCCUS Cockerell**

FIRST STAGE

Body elongate elliptical; caudal margin of abdomen may or may not bulge; segmentation of head, prothorax, and mesothorax ill defined, elsewhere more or less clear; posterior end may or may not be distinctly sclerotic. 8-shaped pores may be prominent or insignificant; partitions may be scarcely in evidence, even through distal bars, at most extending apparently only slightly through tubes; external openings flush with surface; typically 1 to 14 pairs present along marginal, submarginal, and dorsomesal regions of body. A single quinquelocular or trilocular pore associated with each mesothoracic spiracle, but not with metathoracic spiracles. Mesothoracic spiracles open to exterior through a distinct tube arising in vicinity of tracheal collar, but metathoracic spiracles open apparently on surface; spiraculariae may or may not be well defined, strongly sclerotic, or subequal. Either with or apparently without clear area laterad of each metathoracic coxa. Typically 10 or 11 pairs of setae on head, frontal pair

on ventral surface between arms of head skeleton being absent, and 1 to 4 of ventral mesal pairs being long and slender; 3 or 4 pairs on prothorax; 4 to 6 pairs on mesothorax; 3 to 5 pairs on metathorax; none to 4 pairs on each of first to seventh abdominal segments, inclusive; 4 or 6 pairs on posterior abdominal segment. Antenna of the 6-segmented type; basal segment twice as broad, or distinctly less than twice as broad, as any other segment; apical segment moderately elongate. Antennal setae occurring typically as follows: 2 slender setae on basal segment; 1 slender seta and a spinelike process, which apparently may be present or absent, on second segment; 1 seta, either minute or moderately long and slender or fleshy, on third segment; 1 fleshy seta each on fourth and fifth segments; 4 slender and 5 fleshy setae on apical segment. Rostrum apparently with 3 pairs of minute apical setae; rostralis with a single long caudal loop and the small cephalic loop, when uncoiled within body. Legs moderately slender; neither trochanter and femur nor tibia and tarsus fused. Leg setae occurring typically as follows: 5 or 6 setae, including minute basal one, on each procoxa, and only 5 setae each, including minute basal one, on each of other coxae; 2 setae, 1 the minute basal seta, the other comparatively short, on trochanter; none to 2 setae on femur; none or 1 seta on tibia; 3 setae and the spinelike process, which may or may not be evident, on tarsus; 2 setae on claw. Anus small and delicate; on or near ventrocaudal margin; anal ring absent. Male instar puparial.

SECOND-STAGE FEMALE

Body elongate elliptical to pyriform, or largely subcircular; general outline not continued evenly around posterior end, which projects slightly; segmentation, except that of anal valve, obscure or indicated in part on ventral surface of abdomen; membranous except posterior end. Papillae present; numerous or scarce. With 8-shaped pores present or apparently absent; if present, few in number, situated on or near body margin, and delicate; partitions apparently may or may not extend through both bars, but at least no more than very slightly through tubes; bars difficult to distinguish apart; bullae delicate; external openings may or may not be on sclerotic projections. All spiracular pores quinquelocular; of two contrasting sizes, and several of intermediate size may be present; typically 10 to 40 of all sizes associated with each mesothoracic spiracle, and none to 7 of all sizes associated with each metathoracic spiracle; the larger and intermediate-sized ones invaginated and opening on body surface, the smaller ones apparently not invaginated and, together with accompanying spiracles, opening within deep pockets; no other quinquelocular pores on body. Mesothoracic spiracles always open, metathoracic spiracles may or may not open within deep pockets; spiracullariae may or may not be elongate, strongly sclerotic, subequal, or even clearly defined. Body setae scarce; usually 1 pair or none, but not more than 2 pairs, to any one segment except on the 4 posterior abdominal segments; from none to 3 pairs on fifth, none to 4 pairs on sixth, and 1 to 5 pairs on seventh abdominal segment. Antenna limited to a small, rounded, sclerotic piece having 2 minute, slender, partially invaginated setae. Rostrum apparently with at least 2 pairs of minute apical setae; rostralis with 1 elongate loop, 2 large roundish loops, and the characteristic small cephalic loop, when uncoiled within body (data for one species lacking); a membranous area through which rostralis of adult is forced may or may not be evident. Anal valve always present; with characteristic markings either distinct, obscure, or possibly absent; pores lacking, but with from 4 to 7 pairs of setae. Anus situated caudally on anal valve; anal ring apparently absent. Becomes puparium, which may or may not be heavily sclerotic.

ADULT FEMALE

Body moderately or elongate elliptical to pyriform, or largely subcircular; posterior end distinctly projecting beyond general body margin; segmentation obscure, or may be evident on parts of ventral surface and on both surfaces of posterior 3 or 4 segments; in both young and old specimens derm membranous except for some sclerotization of anal segment and parts of ventral surface of seventh abdominal segment, which may also appear slightly sclerotic. Distinct papillae absent. 8-shaped pores distinct; partitions extending through bars, and apparently may extend partially through tubes; bars may be difficult to distinguish apart; bullae delicate; external openings flush with surface and not surrounded by sclerotic rims; localized in region mesad of mesothoracic and ceph-

alad of metathoracic spiracles; may be few in number or moderately abundant. Quinquelocular pores absent. Spiracles flush with surface; spiraculariae moderately elongate or stout, strongly sclerotic, and may or may not be subequal. Body setae few in number and all rather small except perhaps on anal segment; apparently none on head, typically 6 to 21 pairs on thorax and 11 to 28 pairs on abdomen, absent on dorsum except possibly in midthoracic region, marginally on the 4 or 5 posterior abdominal segments, and always on anal segment. Antenna limited to a single sclerotic piece having a pair of small, slender, partially invaginated setae. Rostrum with 1 and possibly 2 minute pairs of apical setae; rostralis with 1 elongate loop, 2 large roundish loops, and the characteristic small cephalic loop, when uncoiled within body. Anal segment on both surfaces of posterior end; partially or wholly sclerotic on dorsum; pores apparently absent; with from 2 to 6 pairs of setae, no more than 1 pair prominent. Anus well up on dorsum; small, almost minute; anal ring apparently absent.

### SECOND-STAGE MALE

Body moderately or elongate elliptical; sides may be almost parallel; segmentation may be practically obscure throughout, in evidence mesally on ventral surface of abdomen, or distinct on both surfaces of abdomen; membranous except for a very slight sclerotization of the 2 posterior abdominal segments, or a heavy sclerotization of the 3 or 4 posterior abdominal segments. Papillae absent or restricted to posterior end, where they are small, rather numerous, and blunt, appearing frequently as hardly more than short irregular lines. 8-shaped pores may be apparently absent or occur along lateral margins of several abdominal segments; very few in number, and very small and delicate; partitions apparently extending no farther than partly through bars, which can be distinguished apart with difficulty; bullae delicate; external openings flush with surface, and not surrounded by sclerotic rims. The asymmetrical type of tubular pore may be present; bar pronounced, tube moderately stout, external opening considerably expanded and not on a projection or surrounded by a sclerotic rim; restricted to two ends of body. None, 1, or 2 quinquelocular pores associated with each mesothoracic, spiracle, but none with metathoracic spiracles; no other quinquelocular or any other pore type present on body. Spiraculariae elongate, strongly sclerotic, subequal. From none to 5 pairs of setae on each of thoracic and abdominal segments except anal segment, which may possess as few as 2 pairs or as many as 6 pairs. Antenna reduced to a flattened, lightly sclerotic, irregularly outlined tubercle, or at most occurring only as a small, rounded, moderately sclerotic tubercle with never more than minute setae present. Rostral setae either obscure or, at most, no more than 2 minute pairs present, these apical in position; rostralis with 1 elongate loop or 2 large roundish loops, in either case also with the characteristic small cephalic loop, when uncoiled within body (data for one species lacking). Legs may or may not be in evidence. Anus minute; may be on caudal margin or distinctly up on dorsal surface; anal ring absent.

### ADULT MALE [8]

Body elongate elliptical, with posterior end occurring as a fairly large, moderately slender, rapierlike projection; segmentation may be nearly complete, with unusually clear definition of segments except for all of anterior section of mesothorax and for the separation of metathorax and second abdominal segment on ventral surface, or obscure on greater part of ventral surface and rather faintly indicated on dorsal surface; anal segment only may be clearly sclerotic, or both eighth abdominal segment and anal segment may be partially sclerotic; vestiges of thoracic wing framework and wings absent. Spiraculariae stout and strongly sclerotic, with metathoracic pair slightly more slender than mesothoracic pair. Body setae absent on ventral surface of thoracic segments and may be absent on the dorsal and ventral surfaces of 3 to 6 abdominal segments. Typically 9 pairs of setae on head, 4 pairs on prothorax, 2 or 4 pairs each on mesothorax and metathorax, and none to 4 pairs on each abdominal segment, with anal segment limited to 3 pairs. Antenna with basal segment rather short on one side; second segment longer than broad; club stout, with either 3 or 4 segments not compactly joined,

[8] Data for one species lacking.

the distal segment being twice as long as any other segment of club; basal and second antennal segments with 2 and 3 small slender setae, respectively; segments of club having either only small fleshy setae, excluding one rather long, slender, apical seta on distal segment, or 2 slender setae on its basal segment and several small, stocky, spinelike setae on each of remaining segments, and, in addition, several rather small fleshy setae and a slender seta on its distal segment. With 2 pairs of eyes, 1 on margin and the other, a distinctly smaller pair, on ventral surface. With a vestige of head skeleton possibly remaining on ventromeson as a differentiated area having a short, inward-projecting piece; invagination of alimentary tube present. Rostrum absent. Legs rather large; size of corresponding segments of each pair and number and character of their setae may be nearly alike, or metathoracic tibiae and tarsi may be appreciably stouter than those of the other pairs, and also prothoracic and metathoracic femora may be stouter than mesothoracic femora; all setae rather small, except perhaps 1 or 2 on each coxa, a distal pair on each tarsus, and the basal pair on claw; typically 5 and 1 slender setae on each coxa and trochanter, respectively, besides the minute basal seta on each; slender, fleshy, or stout spinelike setae on each femur, tibia, and tarsus, ranging in number typically as follows: Femur 4 to 6, tibia 5 to 9, tarsus 5 to 10; definite sensory areas apparently absent. Anus on or near cephalic border of anal segment, or obscure.

Type of genus, *Halimococcus lampas* Cockerell.

### Keys to Species of Halimococcus

#### FIRST STAGE

a. With apparently only one pair of 8-shaped pores on body, situated on margin of second abdominal segment; mesothoracic spiracular pores comparatively large, with star-shaped margins; with no dorsomesal setae on second to seventh abdominal segments, inclusive---------- **lampas** Cockerell.

aa. With 9 or 10 pairs of marginal or submarginal and 1 or more pairs of dorsomesal 8-shaped pores; mesothoracic spiracular pores moderate in size and without star-shaped margins; with one pair of dorsomesal setae each on second to seventh abdominal segments, inclusive.

b. With only one pair of dorsomesal 8-shaped pores normally present; mesothoracic spiracular pores trilocular and slightly invaginated; dorsomarginal setae of ordinary size; basal segment of antenna twice as wide as any other segment---------- **thebaicae** Hall.

bb. With 5 pairs of dorsomesal 8-shaped pores normally present; mesothoracic spiracular pores quinquelocular and appreciably invaginated; dorsomarginal setae conspicuously large and rather stout; basal segment of antenna not twice as wide as any other segment---- **borassi** Green.

#### SECOND-STAGE FEMALE

a. Typically with 7 to 10 small 8-shaped pores, their external openings at the apices of sclerotic projections; mesothoracic spiracles surrounded by a characteristic subtriangular area with roundish margins composed of papillae, spicules, and irregular lines; metathoracic spiraculariae ill defined; covering tissue of anal valve with numerous reticulate or imbricate markings---------- **lampas** Cockerell.

aa. With apparently no more than one pair of 8-shaped pores, their external openings flush with surface and not surrounded by sclerotic rims; mesothoracic spiracles not surrounded by a characteristic differentiated area; metathoracic spiraculariae well defined; covering tissue of anal valve without characteristic markings, at most with only irregular puckers or ridges.

b. Body with numerous pronounced spinelike papillae along margin; typically with 15 or 20 (sometimes more or less) large deeply invaginated quinquelocular pores associated with each mesothoracic spiracle; metathoracic spiracles without accompanying pores and not in pockets; anal valve typically with 7 pairs of setae, 2 mesal pairs being distinctly larger than the others; typical puparium subglobular in form, about 0.9 mm long---------- **thebaicae** Hall.

bb. Body without distinct papillae; with typically 7 or 8 (sometimes more or less) moderately large, moderately invaginated quinquelocular pores associated with each mesothoracic spiracle; typically with from 5 to 12 quinquelocular pores of various sizes associated with each metathoracic spiracle, which is in a distinct pocket; anal valve with only 4 pairs of setae, all subequal and very small; typical puparium elongate in outline, appreciably depressed in cross section and less than 0.6 mm long ..... **borassi** Green.

ADULT FEMALE

a. Mesothoracic spiraculariae distinctly larger than metathoracic pair; 3 pairs of setae in midthoracic region of dorsum; no ventromesal setae between spiracles; dorsal surface of anal segment strongly sclerotic, and entirely so; anal segment with only 4 pairs of setae ..... **lampas** Cockerell.

aa. The 2 pairs of spiraculariae subequal; no dorsal setae on thorax; 2 or more pairs of ventromesal setae between spiracles; dorsal surface of anal segment not entirely sclerotic or, if so, only moderately sclerotic; at least 5 pairs of of setae on anal segment.

b. Body subcircular in outline except for sharply narrowed posterior end; 8-shaped pores clustered almost wholly between 2 pairs of spiracles and rostrum, from 30 to 40 on each side of body; 8 or 9 setae mixed in with each pore cluster; at least 4 pairs of setae on each abdominal segment; anus near cephalic margin of anal segment .. **thebaicae** Hall.

bb. Body elongate elliptical to pyriform in outline; 8-shaped pores clustered mesocephalad of mesothoracic spiracles, from 12 to 18 on each side of body; no setae mixed in with pore clusters; no more than 2 pairs of setae on any abdominal segment except anal one; anus near central part of anal segment ..... **borassi** Green.

SECOND-STAGE MALE

a. Papillae present on the two posterior abdominal segments; tubular pores comparatively large, of the asymmetrical type, and limited to 3 pairs on the two posterior abdominal segments and 1 pair on head; typically with 1 pair of mesothoracic quinquelocular pores, but occasionally none or 2 pairs present ..... **thebaicae** Hall.

aa. Papillae absent; tubular pores minute or absent, when present, apparently of the 8-shaped type and localized along margin of abdomen; all quinquelocular pores absent.

b. All pores apparently absent; with only 2 pairs of setae on anal segment ..... **lampas** Cockerell.

bb. About 4 pairs of minute 8-shaped pores apparently along margin of abdomen cephalad of sclerotic posterior end; with 6 pairs of setae on anal segment ..... **borassi** Green.

ADULT MALE

a. Body margins subparallel laterally and continuing rather evenly around anterior end; head indistinctly delimited; club of antenna 3-segmented, with distal segment tapering to a slender apical projection; all fleshy setae of antenna and legs elongate ..... **lampas** Cockerell.

aa. Body margins tapering perceptibly toward both ends and plainly constricted at suture separating head from thorax; head clearly delimited; club of antenna 4-segmented, with distal segment bluntly rounded at apex; all fleshy setae of antenna and legs short and spinelike ..... **thebaicae** Hall.

HALIMOCOCCUS LAMPAS Cockerell (*2*)

Material from Stanford collection of Coccidae (received through T. D. A. Cockerell); United States Bureau of Entomology (Fuller collection). Both lots from coast of Natal, "on palms", in depressions on sections of leaves.

EGG

(Fig. 27, *F*)

Oviparous. A group of usually about 6, and sometimes as many as 8, spines, rather well spaced and varying slightly in size; sclerotic body derm extending appreciably around spines.

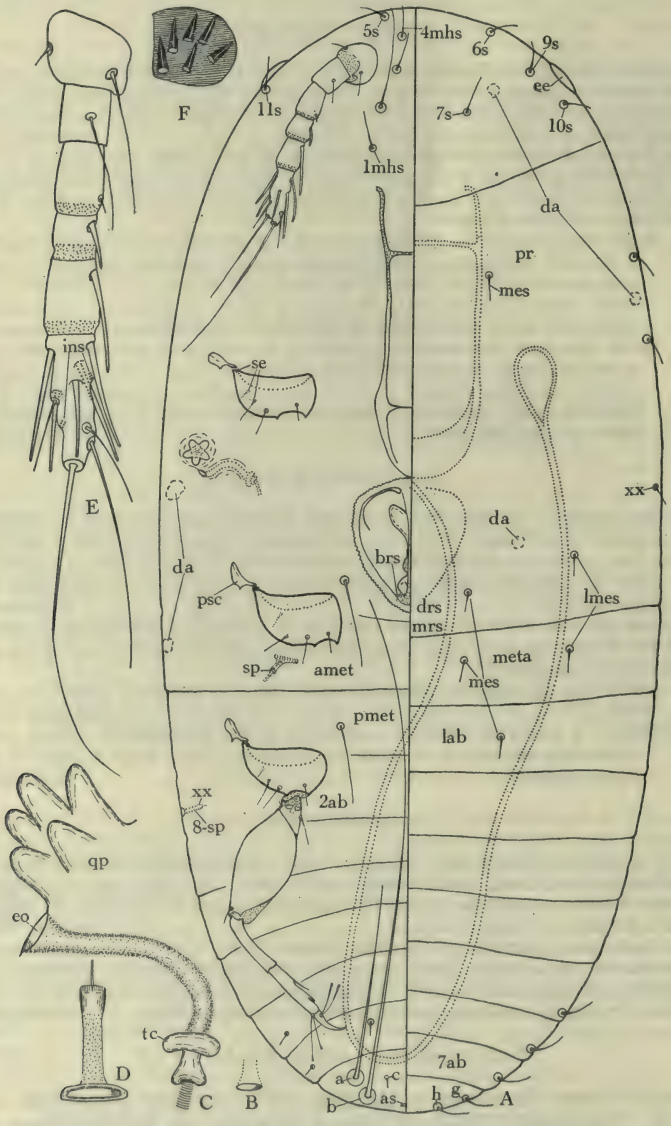


FIGURE 27.—*Halimococcus lampas: A*, First-stage nymph, body, dorsal and ventral, × 500; *B*, same, anus, × 1,500; *C*, same, mesothoracic spiracle, × 2,000; *D*, same, marginal pore, × 3,000; *E*, same, antenna, × 1,000; *F*, egg, spine group, × 1,500.

FIRST STAGE

(Fig. 27, *A–E*)

*Body.*—Rather delicate at first. The following structures apparently absent: Distinct sclerotic areas near head skeleton, distinct furca on meson of thorax, appreciably heavier sclerotization of posterior end, bulge along caudal margin of abdomen, clear area laterad of each metathoracic leg. A newly hatched specimen 0.28 mm long and 0.12 mm wide; a fully developed female specimen 0.50 mm long and 0.20 mm wide. Male puparium rather strongly sclerotic. A typical specimen 0.36 mm long and 0.18 mm wide.

*Pores.*—Only one 8-shaped pair observed, on margin of second abdominal segment; sometimes apparently absent; rather delicate; partitions through bars and tubes obscure; bars difficult to distinguish apart; bullae delicate; external openings large. With dark areas in several places on head and thorax where 8-shaped pores are found in other species. One comparatively prominent quinquelocular pore, having a star-shaped margin, associated with each mesothoracic spiracle.

*Spiracles.*—Mesothoracic pair deeply invaginated, with characteristic curved, rather delicate tubes connecting tracheae with external openings. Mesothoracic spiracullariae obscure or at least not well defined; metathoracic pair irregular in form and lightly sclerotic.

*Body setae.*—Majority prominent. Typically 11 pairs on head, second ventromesal head pair being distinctly larger than the other head setae; 2 marginal pairs and 1 dorsomesal pair on prothorax; 1 marginal, 2 dorsomesal pairs, including what is considered to be a lateromesal pair, and 1 comparatively long ventromesal pair on mesothorax; 2 dorsomesal pairs, including a lateromesal pair, and 1 comparatively long ventromesal pair on metathorax; 1 dorsomesal pair on first abdominal segment; no setae on second, third, and fourth abdominal segments; 1 dorsomarginal pair on fifth, 1 dorsomarginal and 1 small ventromarginal pair on sixth, and 1 dorsomarginal, 1 small ventromarginal, and 1 ventromesal pair on seventh abdominal segment; 5 pairs on posterior abdominal segment; in all, 33 pairs present. Outer and inner long caudal setae in one specimen, 55 and 133 microns long, respectively.

*Antenna.*—Basal segment not twice as broad as any other segment. Two setae, 1 comparatively long, on basal segment; 1 comparatively long seta on second segment, but spinelike process apparently absent; 1 minute seta on third segment; 1 comparatively short fleshy seta on fourth segment; 1 comparatively long fleshy seta on fifth segment; 4 slender and 5 fleshy setae, all comparatively long, on apical segment.

*Rostralis.*—In one typical specimen, 0.75 mm long.

*Legs.*—Coxae slightly broad; femora slightly stout. With 5 setae, including minute basal one, on each coxa; a single seta, apically situated, on femur; none on tibia; 3 setae, but spinelike process apparently absent, on tarsus; 2 setae on claw.

*Exuviation.*—In male the break occurring similarly as in *Palmaricoccus attaleae*, but almost invariably complete, leaving a characteristic differentiated sclerotic band around caudal margin of sixth abdominal segment; head skeleton and rostrum of male simply drop down. Not definitely determined in female.

*Dried material.*—Bright brown in both young and old specimens; naked in appearance; male roundish in cross section.

SECOND-STAGE FEMALE

(Fig. 28)

*Body.*—Moderately elliptical in younger specimens, pyriform in older ones; seventh abdominal segment projecting roundly; segmentation, except for that of anal valve, obscure in younger specimens; distinguished by slightly sclerotic lobules along ventral margin of thorax and abdomen, and with faint indications of sutures on posterior abdominal segments in older specimens; in younger specimens derm membranous except for distinct sclerotization of anal valve; eventually sclerotization spreads over seventh abdominal segment only, before general thickening of derm takes place. With a few small blunt papillae around margin, more easily observed cephalad of mesothoracic spiracles; these papillae obscured in older specimens; membranous areas laterad of head skeleton apparently absent. Puparium only moderately sclerotic. A newly molted specimen 0.36 mm long and 0.16 mm wide; a typical puparium 0.65 mm long and 0.41 mm wide.

*Pores.*—8-shaped pores few in number, usually observed along margin of thorax and abdomen; delicate, rather elongate, subequal; partitions extending through bars but hardly into tubes; external openings on sclerotic conical projections; typically 3 or 4 pairs cephalad and 4 to 6 pairs caudad of mesothoracic spiracles. A varying number of quinquelocular pores, typically about 7 large ones, 1 or 2 intermediate-sized ones, and 7 small ones, associated with each mesothoracic spiracle but none with metathoracic spiracles; the larger ones rather scattered, margins not indented and slightly invaginated; the smallest ones closely grouped and apparently not at all invaginated.

*Spiracles.*—Mesothoracic pair, with accompanying smallest pores, within deep pockets; surrounded by numerous shallow papillae, which extend out of the pockets dorsally, gradually becoming hardly more than slight ridges on dorsum, the whole effect of the papillae about the pockets appearing as a characteristically subtriangular mildly sclerotic area; all, or almost all, quinquelocular pores within these areas, the larger ones mostly along their ventral margin, the intermediate-sized ones near openings into pockets. Metathoracic spiracles open on surface; inconspicuous; unusually mesad in position; spiraculariae of both pairs ill defined.

*Body setae.*—On or near margin, apparently with 1 pair each on prothorax, posterior section of mesothorax, anterior section of metathorax, and fifth and sixth abdominal segments; 2 minute marginal and 3 ordinary-sized marginal pairs on seventh abdominal segment; 2 mesal pairs on dorsum of what is apparently the thorax; 1 minute mesal pair on venter of sixth abdominal segment; 4 pairs on anal valve; in all, 17 pairs present.

*Antenna.*—With two minute setae only, largely invaginated.

*Rostralis.*—In one typical specimen, 2.2 mm long.

*Anal valve.*—Covering tissue distinctly sclerotic, with numerous faint reticulate or imbricate markings which are sometimes obscured; 4 pairs of setae along caudolateral margin, 2 pairs somewhat larger than the others; anus small, distinctly caudad in position, and usually surrounded by thickened tissue; anal ring probably absent.

*Dried material.*—Puparium bright brown; naked except for occasional few waxy filaments; body dome-shaped, almost globular, deeply rounded dorsally and laterally as far ventrad as lobules; posterior end pointed straight dorsad.

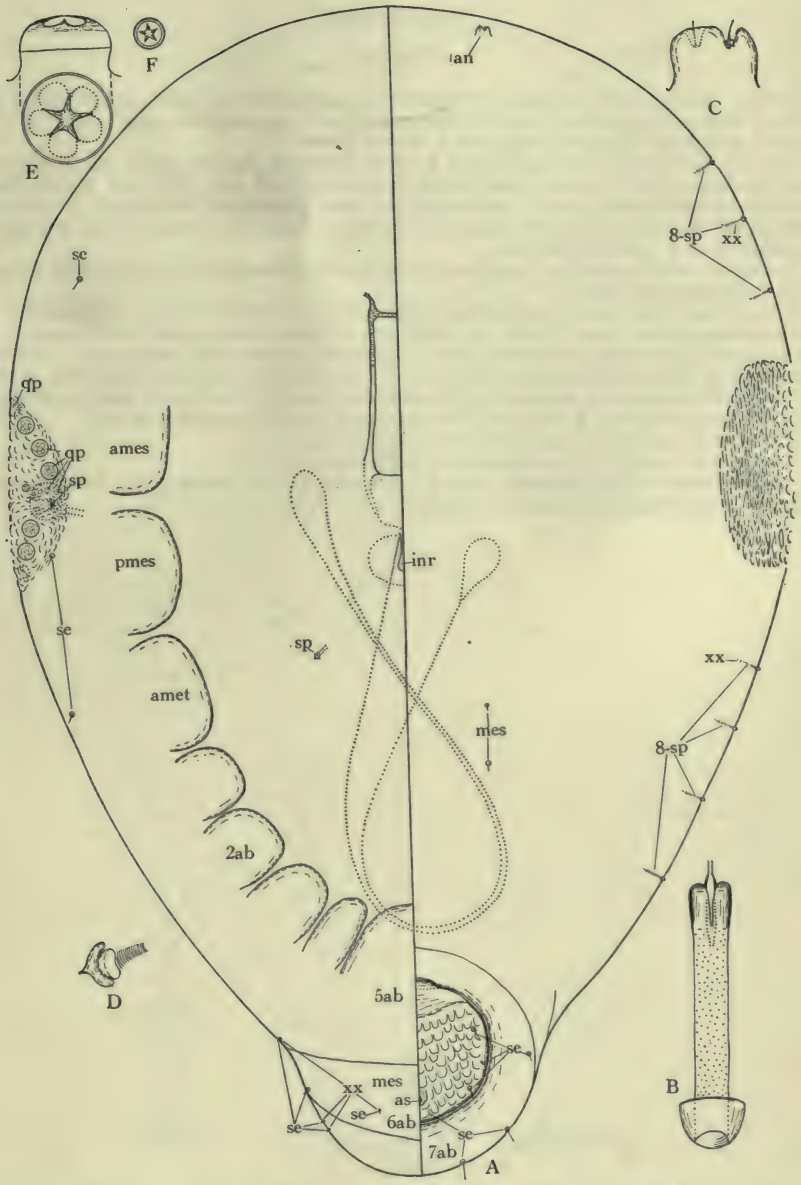


FIGURE 28.—*Halimococcus lampas*, second-stage female: *A*, Body (partially developed), dorsal and ventral, × 300; *B*, marginal 8-shaped pore, × 3,000; *C*, antenna, × 2,000; *D*, metathoracic spiracle, × 2,000; *E*, large quinquelocular pore associated with mesothoracic spiracle, × 2,000; *F*, small quinquelocular pore associated with mesothoracic spiracle, × 2,000.

### THIRD-STAGE FEMALE

Present, but not in condition to distinguish any parts satisfactorily.

### ADULT FEMALE

(Fig. 29)

*Body.*—Moderately elliptical to pyriform; segmentation indistinct except that of anal segment; apparently entire dorsum of anal segment strongly sclerotic. A typical specimen 0.52 mm long and 0.39 mm wide.

*Pores.*—8-shaped pores restricted to area between mesothoracic spiracles and head skeleton and rostrum; partitions extending part way through tubes; bars difficult to distinguish apart; bullae distinct and possessing thickened areas near their inner ends; external openings slightly expanded; 42 counted in the group on one side of one typical specimen.

*Spiracles.*—Spiraculariae moderately elongate; mesothoracic distinctly larger than metathoracic pair.

*Body setae.*—All nearly subequal; apparently absent on head; apparently 1 ventrosubmarginal pair each on prothorax, mesothorax, and metathorax; 1 ventromesal pair each on second, third, and fourth abdominal segments; 1 ventromarginal or submarginal pair each and 1 ventromesal pair each on fifth, sixth, and seventh abdominal segments; 2 dorsomesal and 1 lateromesal pair of dorsum in midthoracic region; 4 pairs on anal segment; in all, 19 pairs present.

*Antenna.*—Essentially as in second-stage female.

*Rostralis.*—In one typical specimen, 3.2 mm long.

*Anal segment.*—Well defined; with 4 pairs of subequal setae along laterocaudal margin; anus slightly cephalad of center.

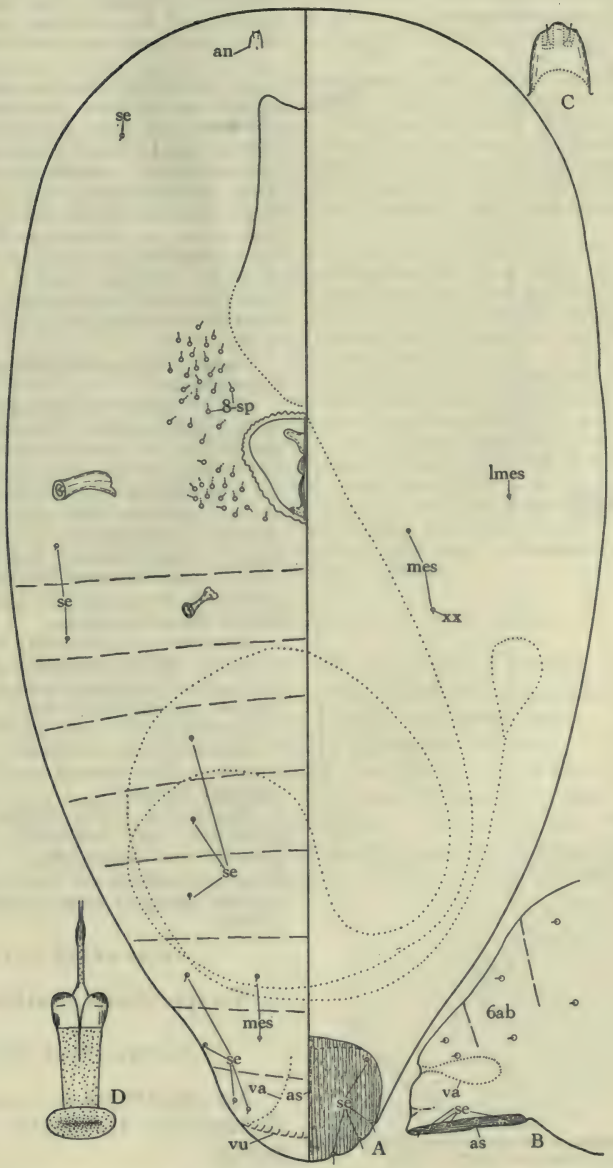


FIGURE 29.—*Halimococcus lampas*, adult female: *A*, Body, dorsal and ventral, × 300; *B*, lateral aspect of posterior end, × 300; *C*, antenna, × 2,000; *D*, midventral 8-shaped pore, × 3,000.

### SECOND-STAGE MALE

(Fig. 30)

*Body.*—Elongate elliptical, with sides nearly parallel; anterior end broadly rounded, posterior end less so; segmentation in evidence mesally on ventral surface caudad of rostrum to and including fourth abdominal segment, elsewhere obscure; membranous except for the four posterior abdominal segments, which are rather sharply differentiated from remainder of body and uniformly moderately sclerotic at first, and uniformly heavily sclerotic toward maturity of instar, though at this time the remainder of the body appears more delicate than when newly molted. Papillae absent. One specimen 0.36 mm long and 0.12 mm wide; another 0.44 mm long and 0.17 mm wide.

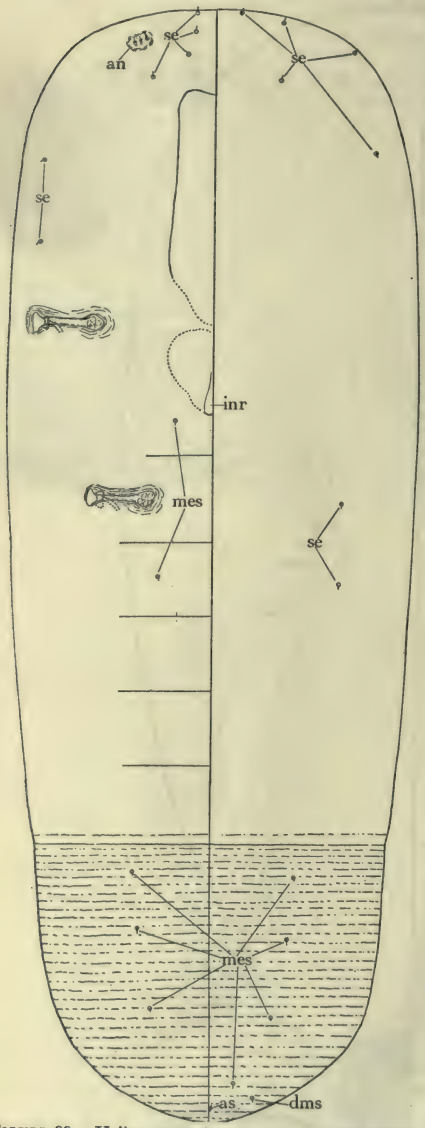


FIGURE 30.—*Halimococcus lampas*, second-stage male: Body, dorsal and ventral, × 350.

*Pores.*—Apparently no pores of any type present.

*Body setae.*—Subequal; typically with 8 pairs on head; 2 ventromarginal pairs and 1 dorsomarginal pair on prothorax; 1 ventromesal pair each on mesothorax, metathorax, and fifth, sixth, and seventh abdominal segments; 1 dorsomesal pair each apparently on metathorax, and first, fifth, sixth, and seventh abdominal segments; 2 dorsal pairs on anal segment; in all, 23 pairs present.

*Antenna.*—Structurally hardly more than a mildly sclerotic thickening, with about 3 minute setae, 2 of which appear to be invaginated.

*Rostralis.*—Not available.

*Legs.*—Not in evidence.

*Anus.*—On dorsal surface near caudal margin.

*Exuviation.*—The heavily sclerotic posterior end projecting from puparium and appearing to break off from remainder of body and to be pushed away at time of emergence of adult.

### THIRD-STAGE MALE

No specimens available.

### FOURTH-STAGE MALE

No specimens in condition to distinguish the parts satisfactorily.

ADULT MALE

(Fig. 31)

*Body.*—Margins subparallel laterally and continuing more or less evenly around anterior end; head indistinctly delimited; segmentation obscure over greater part of ventral surface and not well defined on dorsal surface; anal segment sclerotic, remainder of body membranous. A typical specimen 0.44 mm long and 0.13 mm wide.

*Body setae.*—Small except second ventromesal head pair and 2 pairs on anal segment; typically 4 ventral and 5 dorsal pairs on head, 3 marginal or submarginal pairs and 1 dorsomesal pair on prothorax, 1 dorsomesal and 1 lateromesal pair of dorsum each on mesothorax and metathorax, 1 dorsomesal pair each on first and fifth to eighth abdominal segments, inclusive, 1 marginal pair each on sixth and seventh, 2 marginal pairs on eighth, 1 apparently ventromesal pair each on seventh and eighth abdominal segments, and 3 pairs on anal segment; in all, 31 pairs present.

*Antenna.*—Club with three segments only, its distal segment tapering apically to a fine projection capped by a long slender seta; all other setae of club fleshy in structure and rather small and short, except possibly 4 or 5 of varying lengths near apex of distal segment. Setae of club occurring typically as follows: 4 in a whorl near apex of first segment, 6 near apex of middle segment, and 18, excluding slender apical one, scattered over distal segment.

*Legs.*—Subequal; femora stout, the mesothoracic pair appearing slightly less so than the other 2 pairs; tibiae and tarsi noticeably slender, with tarsi distinctly elongate and appreciably longer than tibiae; metathoracic tibiae and tarsi very slightly stouter than those of other 2 pairs, with tibiae slightly shorter and tarsi slightly longer than those of other 2 pairs; number and character of setae of corresponding segments of each pair nearly alike; each coxa with a comparatively long seta on its inner margin, each femur with 2 slender and 2 rather small fleshy setae, each tibia with 4 slender and 2 small fleshy setae, each tarsus with 3 or 4 rather short slender setae, and a pair of long slender ones near its outer distal margin.

*Anus.*—On or near cephalic border of anal segment.

HALIMOCOCCUS THEBAICAE Hall (*8, pp. 2–3*)

Material collected in 1924 by W. J. Hall, Karnak, Egypt, on doum palm (*Hyphaene thebaica*); also collected by him at Luxor, Nag-Hamadi, and Motana, Upper Egypt, on same palm. Mixed in with downy mass of brownish-white filaments of host, "literally in millions" in this matter, according to Hall, and "the growth of which is apparently induced by the insect attack"; also on under surface of leaves, particularly near midrib. Material also from E. E. Green, F. Laing, and United States Bureau of Entomology, presumably from same source, a part of type material collected by W. J. Hall, Luxor, Egypt, 1922.

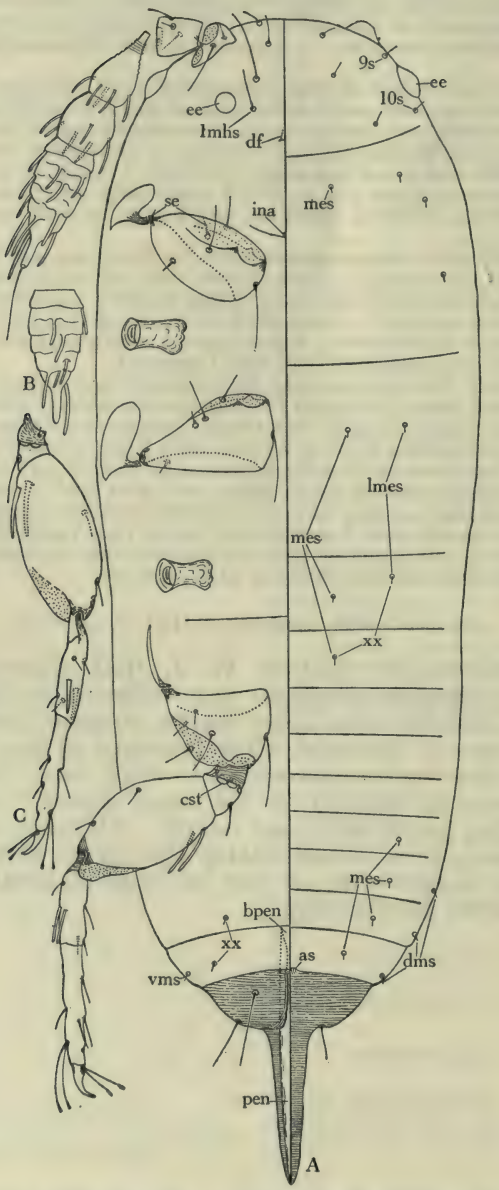


FIGURE 31.—*Halimococcus lampas*, adult male *A*, Body, dorsal and ventral; *B*, antenna, dorsal surface of apical segment; *C*, prothoracic leg. × 350.

EGG

(Fig. 32, *G*)

Oviparous. With a group of from 6 to 10, usually 7 or 8, spines, rather well spaced and varying considerably in size; sclerotic body derm extending appreciably around spines.

FIRST STAGE

(Fig. 32, *A–F*)

*Body.*—Not delicate. With distinct sclerotic areas near head skeleton. A faintly discernible pair of furcae on each side of meson between mesothorax

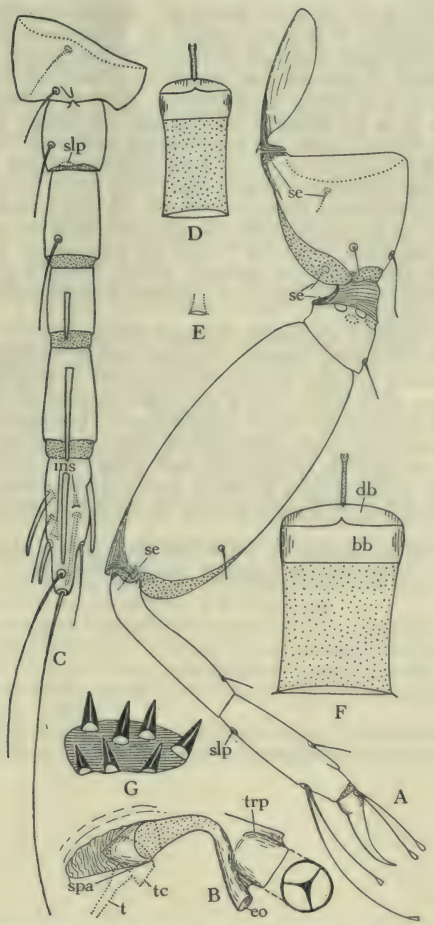


FIGURE 32.—*Halimococcus thelaxicae: A*, First-stage nymph, metathoracic leg, × 1,000; *B*, same, mesothoracic spiracle, × 2,000; *C*, same, antenna, × 1,000; *D*, same, head pore, × 3,000; *E*, same, anus, × 1,500; *F*, same, caudodorsal 8-shaped pore, × 3,000; *G*, egg, spine group, × 1,500.

and metathorax. In younger individuals the two posterior abdominal segments slightly sclerotic; in older ones of both sexes appreciably sclerotic, with sclerotization extending in a decreasing degree cephalad over the next segment or so. Typically a slight bulge on each side and a more pronounced one on meson along caudal margin. Clear area present laterad of each metathoracic coxa. In female the body becomes much swollen, except the two posterior segments, producing a characteristic appearance. A typical newly hatched specimen 0.36

mm long and 0.12 mm wide; a fully developed female 0.46 mm long and 0.23 mm wide; male puparium only moderately sclerotic, typically 0.36 mm long and 0.18 mm wide.

*Pores.*—8-shaped pores prominent; relatively broad; progressively larger caudad on the three posterior abdominal segments; partitions indistinct, extending through no more than distal bars, which are difficult to distinguish; bullae delicate. Twelve 8-shaped pores typically present as follows: 2 marginal pairs each on head and anterior section of mesothorax; 1 marginal pair on metathorax and on first, second, and fifth to eighth abdominal segments, inclusive; 1 dorsomesal pair on second abdominal segment. A slightly invaginated trilocular pore associated with each mesothoracic spiracle.

*Spiracles.*—Invaginated tubes of mesothoracic pair connecting trachea to exterior only moderate in length; spiraculariae of both pairs moderately sclerotic, not elongate, subequal.

*Body setae.*—Eleven pairs of head setae, in number and character essentially as in *Halimococcus lampas;* 3 marginal pairs on prothorax, 2 marginal pairs on metathorax, 1 marginal pair each on apparently the anterior section of mesothorax, posterior section of mesothorax, and first to seventh abdominal segments, inclusive; 1 dorsomesal pair each on prothorax, posterior section of mesothorax, metathorax, and on first to seventh abdominal segments, inclusive; 1 pair of lateromesal setae of dorsum each on mesothorax and metathorax; 1 ventrosubmarginal pair each on second to seventh abdominal segments, inclusive; 1 ventromesal pair each on mesothorax, metathorax, and seventh abdominal segment; 6 pairs on posterior abdominal segment; in all, 52 pairs present. In one specimen, outer and inner long caudal setae, 62 and 195 microns long, respectively.

*Antenna.*—Basal segment twice as broad as any other segment. All setae approximately as in *Halimococcus lampas*, except that a spinelike process on second segment is distinct and one long slender seta, instead of a minute seta, is present on third segment.

*Rostralis.*—In one typical specimen, 1.1 mm long.

*Legs.*—Coxae not relatively broad; femora rather elongate. In essentials, setae as in *Halimococcus lampas*, except for presence of 6 setae on each procoxa, 2 on each femur, 1 on each tibia, and a spinelike process on tarsus.

*Exuviation.*—Male essentially as in *Halimococcus lampas* except with no pronounced sclerotic band on sixth abdominal segment; female becoming much swollen, eventually rupturing irregularly but largely around margins, usually leaving some ventral skin, except antenna and posterior end, in a single piece; head skeleton and rostrum of female simply dropping down to about the line of metathoracic legs.

*Dried material.*—Bright brown in both old and young specimens; practically naked in appearance; male instar roundish in cross section.

### SECOND-STAGE FEMALE

(Fig. 33, *A–F*)

*Body.*—Moderately elliptical in younger specimens to pyriform or subcircular in older ones, except for posterior end, which is sharply constricted in the latter; seventh abdominal segment projecting less roundly than in *Halimococcus lampas*, being in its entirety characteristically subtriangular, apex of triangle constituting caudal margin of body; segmentation obscure except that of anal valve, and possibly the 2 or 3 other posterior abdominal segments; in younger specimens derm membranous except that of anal valve and seventh abdominal segment; latter strongly sclerotic; sclerotization spreading slightly cephalad in decreasing degree, before general thickening of body wall takes place. Numerous distinct spinelike papillae along margin and ventrosubmargin from about the fifth or sixth abdominal segment almost, if not quite, to head; cephalic margin of body practically free of papillae; mesothoracic but not metathoracic spiracles within papillary area; papillae surrounding spiracles irregular in form, mostly platelike, typically with serrated borders. A membranous area through which rostralis of adult is forced present on meson cephalad of rostral slit. Puparium heavily sclerotic. A typical newly molted specimen 0.47 mm long and 0.20 mm wide; a moderately large puparium 0.9 mm long and 0.6 mm wide.

*Pores.*—8-shaped pores apparently absent. A varying number of quinquelocular pores associated with each mesothoracic spiracle, but none with metathoracic spiracles; on one side of one typical specimen occurred 22 deeply invaginated large pores, 4 invaginated intermediate-sized ones, and 14 noninvaginated small ones; large pores widely scattered along margin and ventrosubmargin, appearing in some specimens to reach almost to head or to posterior end; intermediate-sized ones situated near external openings to pockets; small ones bunched within latter; margins of large and intermediate-sized pores slightly indented.

*Spiracles.*—Mesothoracic spiracles with accompanying small pores open into clearly defined pockets, which are almost globular; metathoracic spiracles open on surface. Spiracullariae much enlarged at their inner ends, but rather slender toward spiracles; both pairs distinctly sclerotic, subequal.

*Body setae.*—Apparently none present on dorsum except possibly on or near margin of posterior 3 or 4 abdominal segments. Typically 1 pair mesad of and 1 or 2 pairs immediately caudad of mesothoracic spiracles; 1 pair near margin laterad of metathoracic spiracles; 1 marginal pair each on third and fourth abdominal segments; 2 marginal pairs on fifth abdominal segment; 3 more or less marginal pairs each on sixth and seventh abdominal segments; 1 ventromesal pair each on fourth to seventh abdominal segments, inclusive; 7 pairs on anal valve; in all, 24 or 25 pairs present.

*Antenna.*—With two small partially invaginated setae only.

*Rostralis.*—In one typical specimen, 2.9 mm long.

*Anal valve.*—In younger specimens covering tissue slightly sclerotic around margins, membranous elsewhere; distinctive markings obscure or absent. With 5 rather small pairs of setae along caudolateral margin and 2 distinctly larger mesal pairs. Anus caudally located; rather small; surrounding tissue thickened, but anal ring probably absent.

*Dried material.*—Puparium dark to blackish brown; naked in appearance; unusually thick, almost globular; posterior end characteristically curved dorsocephalad.

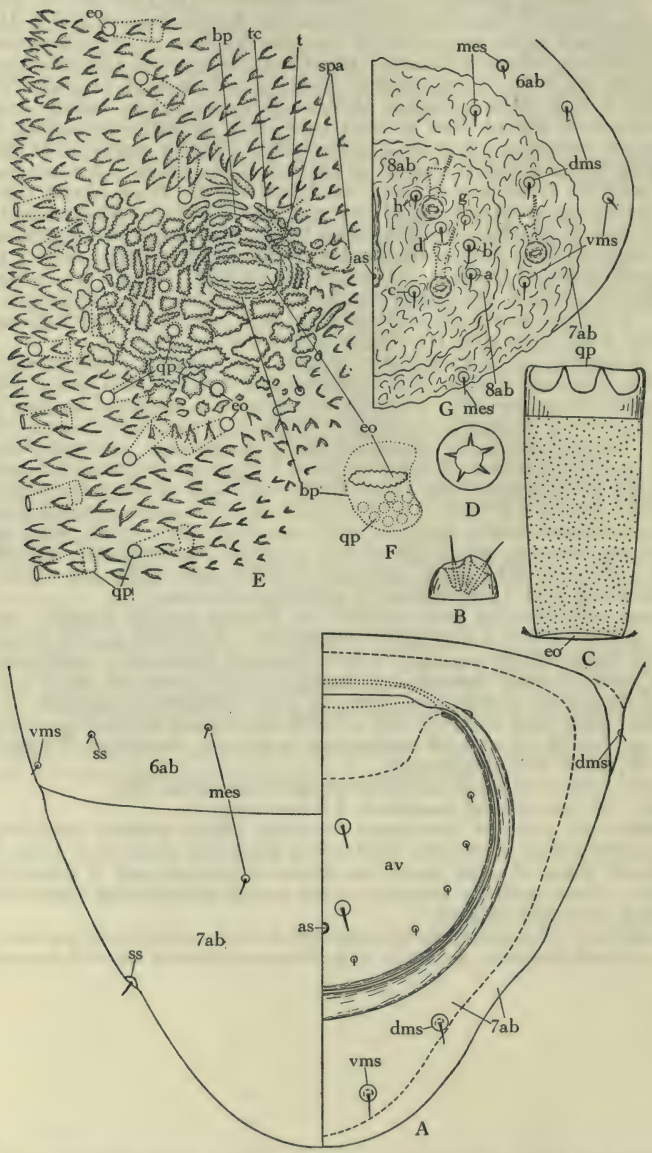


FIGURE 33.—*Halimococcus thebaicae: A*, Second-stage female, posterior end, dorsal and ventral × 500; *B*, same, antenna, × 2,000; *C*, same, large mesothoracic quinquelocular pore, × 2,000; *D*, same, small mesothoracic quinquelocular pore, × 2,000; *E*, same, mesothoracic region, × 500; *F*, same, outline of mesothoracic spiracular pocket, × 500; *G*, second-stage male, posterior end, dorsal, × 1,000.

### THIRD-STAGE FEMALE

(Fig. 34, *E* and *F*)

Subglobular in mass except for sharply narrowed posterior projection; derm membranous but firm; tubercles or other pronounced dermal configurations, such as pore impressions, apparently absent. Mesothoracic spiracles, slightly larger than metathoracic spiracles; each with a single trachea and a brush of tracheoles, those of the mesothoracic spiracles being distinctly the larger. With a distinct roundish area on meson through which rostralis of adult is forced.

### ADULT FEMALE

(Fig. 34, *A–D*)

*Body.*—Subglobular in appearance except for a sharply narrowed posterior end; segmentation obscure except that of the two posterior segments; anal segment partially or entirely sclerotic, also ventrocaudal region of seventh abdominal segment. A typical specimen 0.82 mm long and 0.62 mm wide.

*Pores.*—8-shaped pores closely bunched between the 2 pairs of spiracles and rostrum; partitions extending only through tubes; bars difficult to distinguish apart; external openings much expanded; typically 30 to 40 on each side of body.

*Spiracles.*—Both pairs of spiraculariae stout; mesothoracic pair slightly larger than metathoracic pair.

*Body setae.*—Approximately subequal; apparently absent on dorsum except for 1 pair each on margin of third to sixth abdominal segments, inclusive, and 5 pairs on anal segment. On venter, 1 submarginal pair apparently on prothorax; 1 marginal. 2 submarginal, and 8 or 9 scattered pairs mixed in with 2 groups of pores on mesothorax; 4 marginal, 2 submarginal, and 2 mesal pairs on metathorax; 4 pairs on second and 3 pairs each on third to seventh abdominal segments, inclusive; in all, 48 or 49 pairs present.

*Antenna.*—Comparatively large; with one pair of slender partially invaginated setae, and with apparently a single minute spinelike seta.

*Rostralis.*—In two specimens, 4.91 and 5.69 mm long, respectively; tips of two of its component parts each with about 4 minute teeth projecting backwards.

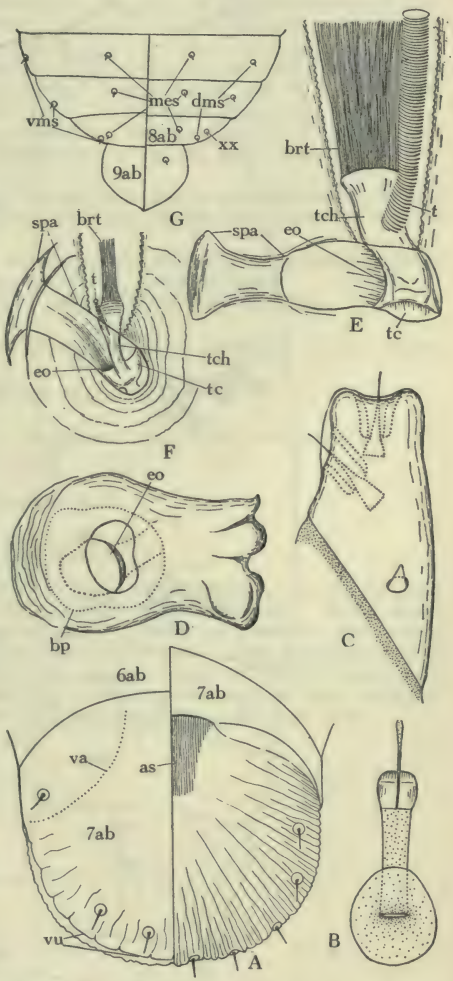


FIGURE 34.—*Halimococcus thebaicae: A*, Adult female, posterior end, dorsal and ventral, × 450; *B*, same, midventral 8-shaped pore, × 3,000; *C*, same, antenna, × 1,500; *D*, same, mesothoracic spiracle, × 750; *E*, third-stage female, mesothoracic spiracle, × 750; *F*, same, metathoracic spiracle, × 750; *G*, fourth-stage male, posterior end, dorsal and ventral, × 450.

*Anal segment.*—Slightly sclerotic in general, with a heavier sclerotization around anus; lateral and caudal margins faintly crenulate; vulva extending nearly to caudal margin; five pairs of subequal setae along laterocaudal margin. Anus distinctly cephalad in position.

SECOND-STAGE MALE

(Figs. 33, *G*, and 35)

*Body.*—Moderately to somewhat elongate elliptical; anterior end rounded, posterior end mildly truncated; segmentation rather distinct on both surfaces

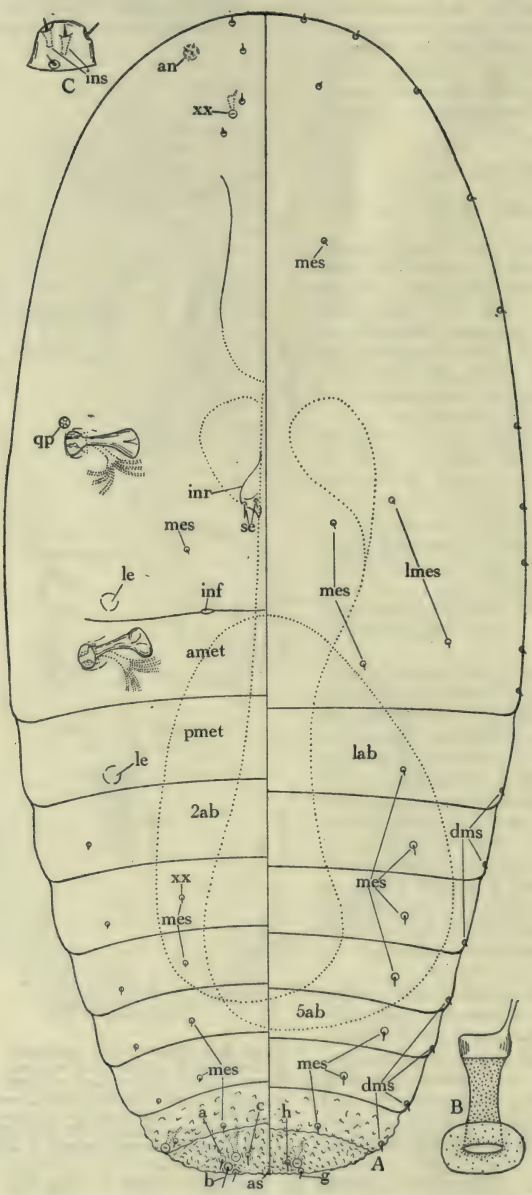


FIGURE 35.—*Halimococcus thebaicae*, second-stage male: *A*, Body, dorsal and ventral, × 450; *B*, invaginated pore (asymmetrical), × 3,000; *C*, antenna, × 2,000.

of abdomen; membranous except for slight sclerotization of the two posterior abdominal segments. Papillae present but delicate, frequently appearing as hardly more than short irregular lines; restricted to both surfaces of the two

posterior abdominal segments, being more numerous on anal than on preceding segment. A typical specimen 0.34 mm long and 0.15 mm wide.

*Pores.*—8-shaped pores absent. Asymmetrical pores present, subequal; restricted to head and the 2 posterior abdominal segments; typically 1 pair on ventral surface of head, 1 marginal pair on seventh abdominal segment, and 1 mesal pair on each surface of anal segment. Either none, 1, or 2 quinquelocular pores associated with each mesothoracic spiracle, but none with metathoracic spiracles.

*Body setae.*—Subequal except for 1 ventromarginal pair on anal segment. Typically 8 pairs scattered on head; 2 marginal pairs and 1 dorsomesal pair on prothorax; 3 marginal pairs, 1 dorsomesal and 1 lateromesal of dorsum, and 1 ventromesal pair on mesothorax; 2 marginal pairs, 1 dorsomesal and 1 lateromesal pair of dorsum, on metathorax; 1 marginal and 1 dorsomesal pair on first abdominal segment; 1 marginal, 1 dorsomesal, and 1 ventromarginal pair on each of second to seventh abdominal segments, inclusive, and in addition 1 ventromesal pair on third to seventh abdominal segments, inclusive; anal segment with 6 pairs; in all, 52 pairs present.

*Antenna.*—Varying from a shallow mildly sclerotic disk to a moderately sclerotic rounded tubercle; with apparently 2 minute surface setae and a pair of minute partially invaginated setae.

*Rostralis.*—With two large roundish loops and the characteristic small cephalic loop, when uncoiled within body; in one specimen, 1.8 mm long.

*Legs.*—May or may not be in evidence; always extremely vestigial.

*Anus.*—On caudal margin.

*Exuviation.*—All of derm pushed to one side as a shapeless mass within puparium.

### THIRD-STAGE MALE

Available material too delicate to distinguish the parts adequately. One specimen 0.33 mm long and 0.16 mm wide.

### FOURTH-STAGE MALE

(Figs. 34, *G*, and 36, *F*)

Body moderately elliptical, with posterior end a short, stocky, slightly pointed projection; segmentation of body and appendages distinguishable. Body setae about as in adult male, except submarginal setae of latter on posterior abdominal segments apparently replaced by mesal ones in this stage. Legs proportionately longer and not so elbowed as in *Palmaricoccus attaleae;* each with two pronounced fleshy apical projections for holding the pair of developing apical tarsal setae of subsequent instar. A typical specimen 0.37 mm long and 0.17 mm wide.

ADULT MALE

(Fig. 36, *A–E*)

*Body.*—Margins tapering perceptibly toward both ends and plainly constricted at the suture separating head from thorax, so that head is plainly delimited.

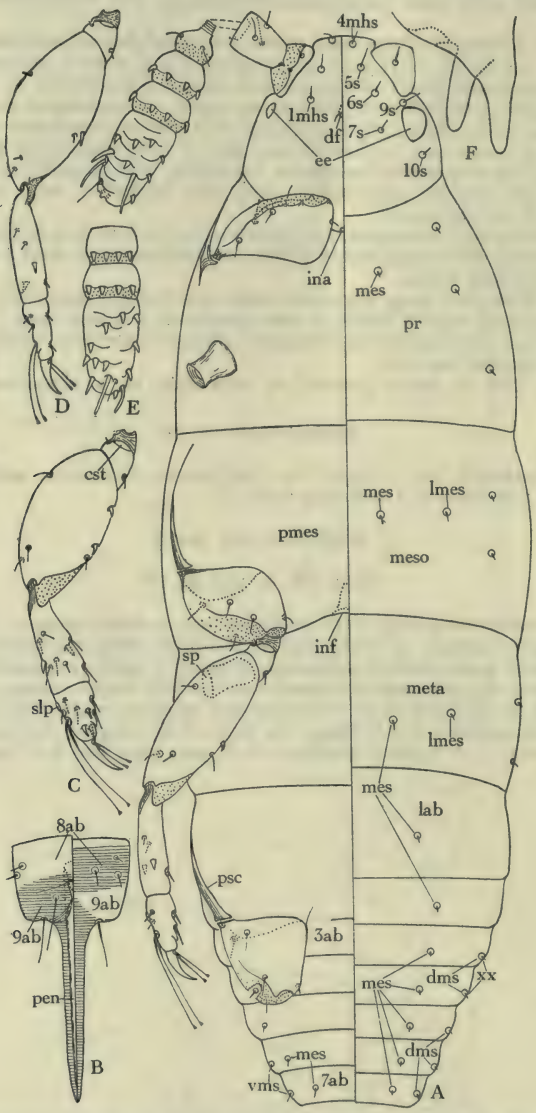


FIGURE 36.—*Halimococcus thebaicae: A*, Adult male, body, dorsal and ventral, × 400; *B*, same, posterior end, dorsal and ventral, × 400; *C*, same, metathoracic leg, × 400; *D*, same, prothoracic leg, × 400; *E*, same antenna, dorsum of apical part, × 400; *F*, fourth-stage male, tip of ventral surface of metathoracic leg, × 1,000.

Eighth abdominal segment and anal segment each partially sclerotic, and separation between the two obscure; segmentation of remaining segments pronounced, except no evidence on either surface of anterior section of mesothorax or of a suture between metathorax and second abdominal segment on ventral surface. One typical specimen 0.45 mm long and 0.12 mm wide.

*Body setae.*—Distinct, subequal, except that the 3 pairs on anal segment are appreciably longer than the other body setae; typically 3 and 6 pairs on ventral and dorsal surfaces of head, respectively; 3 marginal pairs and 1 dorsomesal pair on prothorax; 2 marginal pairs, the lateromesal pair of dorsum, and 1 dorsomesal pair on mesothorax and metathorax each; 1 dorsomesal pair on each of first to eighth abdominal segments, inclusive, 1 marginal pair each on third to eighth, inclusive, 1 ventromarginal pair each on fourth to eighth, inclusive, 1 ventrosubmarginal pair each on sixth, seventh, and eighth, 1 additional marginal pair on eighth, and 1 ventromesal and 2 marginal pairs on anal segment; in all, 47 pairs present.

*Antenna.*—Club with four segments, distal segment bluntly rounded apically. Club setae occurring typically as follows: 2 slender setae on first segment; 8 short, stout, spinelike setae each in a whorl near apical margins of second and third segments; 17 short, stout, spinelike setae, 6 small fleshy setae, and 1 small slender seta, all irregularly scattered, on distal segment.

*Legs.*—Prothoracic and metathoracic femora subequal and noticeably stouter than mesothoracic femora; prothoracic and mesothoracic tibiae and tarsi subequal and noticeably more slender than metathoracic tibiae and tarsi; tibiae and tarsi of all pairs distinctly less slender than in *Halimococcus lampas;* all tibiae appreciably longer than tarsi; no setae on coxae appreciably long, those on the other segments, except the distal pair on tarsus and the pair on claw, either slender and short or short, stocky, and spinelike. Number and character of setae on corresponding segments of prothoracic and mesothoracic legs practically alike, but setae less numerous than on corresponding segments of metathoracic pair; typically with 4 slender and 1 or 2 spinelike setae on each femur, 3 or 7 slender and 2 spinelike setae on each tibia, and 4 or 5 short, slender setae and none or 3 spinelike setae on each tarsus.

*Anus.*—Obscure.

### HALIMOCOCCUS BORASSI Green (*6*)

Material from E. E. Green, exposed on leaves of "Palmyra palm" (*Borassus flabellifer*), Peradeniya, Ceylon; United States Bureau of Entomology, exhibit collection Green, presumably same lot.

#### EGG

(Fig. 37, *J*)

Oviparous. With a group of 3 or 4 spines, moderately spaced and varying but little in size; sclerotic body derm extending slightly around spines.

#### FIRST STAGE

(Fig. 37, *A–I*)

*Body.*—Large compared with that of adult female. Rather rugose on dorsum. Posterior end not distinctly sclerotic. Caudal margin without bulge. With

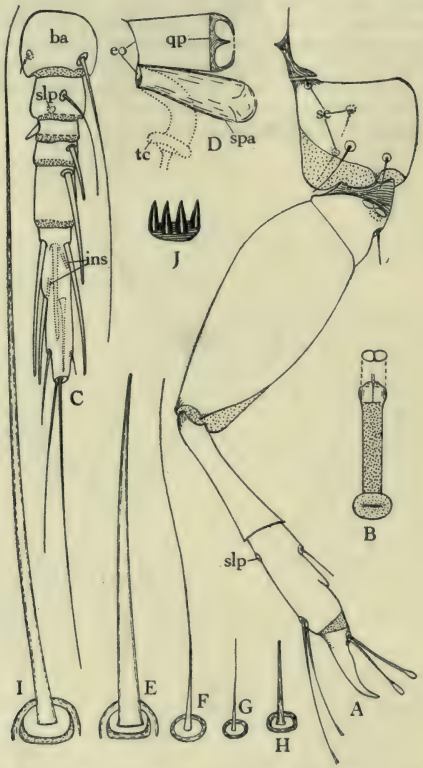


FIGURE 37.—*Halimococcus borassi: A*, First-stage nymph, metathoracic leg, × 1,000; *B*, same, dorsocaudal 8-shaped pore, × 3,000; *C*, same, antenna, × 1,000; *D*, same, mesothoracic spiracle, × 2,000; *E*, same, dorsomarginal seta, × 2,000; *F*, same, third head seta, × 2,000; *G*, same, ventromesal seta of posterior segment, × 2,000; *H*, same, dorsomesal seta, × 2,000; *I*, same, smaller, long caudal seta, × 2,000; *J*, egg, spine group, × 1,500.

clear area laterad of each metathoracic coxa. A typical newly hatched specimen 0.25 mm long and 0.11 mm wide. Male puparium uniformly heavily sclerotic; typically 0.38 mm long and 0.13 mm wide.

*Pores.*—All 8-shaped pores comparatively small; partitions distinguishable through bars but not through tubes; bars difficult to distinguish apart; bullae delicate. Three pairs of 8-shaped pores on head, 1 dorsomesal pair on each section of mesothorax, metathorax, and second abdominal segment; 1 marginal pair each on prothorax, anterior sections of mesothorax and metathorax, posterior section of metathorax and fifth, sixth, and eighth abdominal segments; in all, 14 pairs present. One distinctly invaginated quinquelocular pore associated with each mesothoracic spiracle, but none with metathoracic spiracles.

*Spiracles.*—Mesothoracic invaginated tube rather short; spiracularlae of both pairs slightly elongate, strongly sclerotic, subequal.

*Body setae.*—A row of rather large spinelike setae along dorsal margin as follows: 4 pairs on head; 2 pairs each on prothorax, metathorax, and eighth abdominal segment; 1 pair each on all other thoracic and abdominal segments. One dorsomesal pair of setae present on head and each segment of thorax and abdomen, except anterior section of mesothorax; 1 small marginal pair on head; apparently 1 lateromesal pair of dorsum on prothorax; 4 rather long ventromesal pairs on head; 1 ventromesal pair each on mesothorax, metathorax, and seventh and eighth abdominal segments; 2 long caudal pairs on eighth abdominal segment; in all, 43 pairs present. Outer and inner long caudal setae in one specimen, 39 and 125 microns long, respectively, the smaller pair twice or more the length of the prominent dorsomarginal setae.

*Antenna.*—Basal segment not twice as broad as any other segment; third and fourth segments comparatively small. In structure and occurrence all setae essentially as in *Halimococcus lampas*, except that the spinelike process is distinct on second segment and there is a noticeably short and fleshy seta on third segment.

*Rostralis.*—In one typical specimen, 0.51 mm long.

*Legs.*—Coxae not broad; setae essentially as in *Halimococcus lampas* except apparently none on femur, and spinelike process of tarsus faint.

*Exuviation.*—In male, head skeleton and rostrum simply drop down, and dorsal part of the four posterior abdominal segments is sloughed; in female, parts of marginal and ventral surfaces are ruptured, leaving practically the entire dorsum intact, and generally on one side the lateral and ventral parts, to and including the legs, are left attached to the dorsum, making a single shell that serves as covering for puparium.

*Dried material.*—Rich brown in younger specimens to almost black in fully developed ones; naked in appearance; male instar roundish in cross section.

SECOND-STAGE FEMALE

(Fig. 38, *A–E*)

*Body.*—Elongate elliptical, seventh abdominal segment subtriangular, but margins more rounded than in *Halimococcus thebaicae;* surface much convoluted, especially along margin, in all prepared material; segmentation obscure except for definition of anal valve; membranous in younger specimens except for slight sclerotization of seventh abdominal segment; eventually latter becoming strongly sclerotic, and a mild sclerotization spreading to sixth abdominal segment before general thickening of body wall takes place. Papillae apparently absent, though convolutions of derm frequently resemble them. A membranous area near head skeleton for penetration of adult rostralis apparently absent. Puparium heavily sclerotic laterally and dorsally, but largely membranous ventromesally; sclerotic

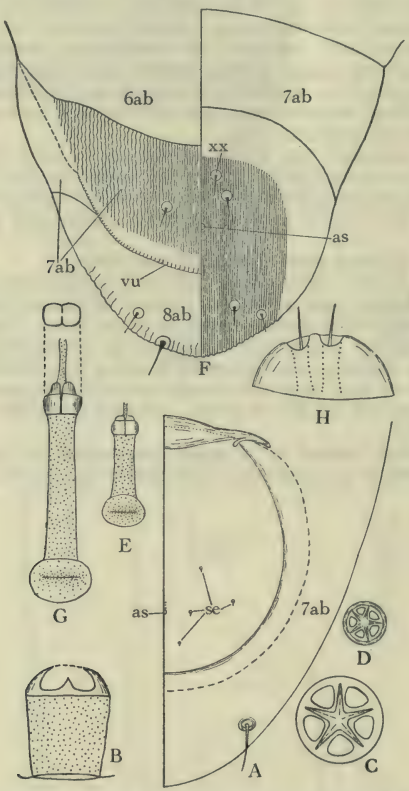


FIGURE 38.—*Halimococcus borassi: A*, Second-stage female, posterior end, dorsal, × 500; *B*, *C*, same, large quinquelocular pore, lateral and end views, × 2,000; *D*, same, small quinquelocular pore, end view, × 2,000; *E*, same, 8-shaped pore, × 3,000; *F*, adult female, posterior end, dorsal and ventral, × 500; *G*, same, midventral 8-shaped pore, × 3,000; *H*, same, antenna, × 2,000.

derm rugose. A typical newly molted specimen 0.44 mm long and 0.10 mm wide; a puparium 0.66 mm long and 0.22 mm wide.

*Pores.*—At least 1 pair of minute 8-shaped pores on ventromesal surface of head; no others definitely distinguished on body; partitions extending through bars but hardly into tubes; bars can be distinguished apart; external openings on surface. A varying number of quinquelocular pores associated with each pair of spiracles; in one specimen 8 and 8 large ones, 3 and 1 intermediate-sized ones, and 5 and 6 small ones associated with mesothoracic spiracles of each side, respectively; in same specimen 5 and 7 large ones, no intermediate-sized ones, and 4 and 4 small ones associated with metathoracic spiracles on corresponding sides, respectively. In a count of 9 groups of quinquelocular pores on mesothorax, the range in number was 4 to 13 for the large ones separately, and 5 to 11

for all the others together, the average being 7.7 in each case; similarly, in 6 groups on metathorax, the range was 2 to 7 and 3 to 5, the average 5.8 for the large ones separately and 4.0 for all the others together. The intermediate-sized quinquelocular pores not much larger than the small ones; the large pores without indented margins and only moderately invaginated; all grouped fairly close about their respective spiracles.

*Spiracles.*—Both pairs of spiracles opening into pockets, having relatively large external openings, which are at the inner ends of pronounced depressions leading to body margin.

*Body setae.*—Typically 1 ventrosubmarginal pair immediately caudad of each pair of spiracles; 1 ventromesal pair between mesothoracic spiracles; 1 rather large pair near caudal margin of seventh abdominal segment; 4 pairs on anal valve; in all, 8 pairs present.

*Antenna.*—Essentially as in *Halimococcus lampas.*

*Rostralis.*—Not available.

*Anal valve.*—Covering tissue in younger specimens largely membranous, with no characteristic markings; in prepared specimens inclined to pucker or ridge up; with apparently four minute pairs of setae, all situated away from margin, in vicinity of anus; latter minute; anal ring absent.

*Dried material.*—Puparium nearly black; naked in appearance; sides slightly rounded in cross section; body more cylindrical than dome-shaped, posterior end pointed nearly straight dorsad.

### THIRD-STAGE FEMALE

Present, but available material not in condition to distinguish any parts satisfactorily.

### ADULT FEMALE

(Fig. 38, *F–H*)

*Body.*—Elongate elliptical; segmentation distinguished on ventral surface of thorax caudad of rostrum, on abdomen, and on dorsum of the 3 or 4 posterior abdominal segments; anal segment partially sclerotic, and ridged effect on ventral surface of seventh abdominal segment giving the parts the appearance of being sclerotic. A typical specimen 0.58 mm long and 0.28 mm wide.

*Pores.*—8-shaped pores apparently limited to the region between mesothoracic spiracles and head skeleton; partitions extending apparently only through bars; bars rather easily distinguished apart; external openings slightly expanded; typically 12 to 18 pairs present.

*Spiracles.*—Spiracular rather stout, subequal.

*Body setae.*—All approximately subequal except for 1 pair on caudal margin of anal segment. None observed dorsally except 3 pairs on anal segment. On venter, typically 1 submarginal pair and 2 or 3 mesal pairs on apparently the posterior section of mesothorax; 1 submarginal and 1 mesal pair on posterior section of metathorax; 1 mesal pair each on second to seventh (excluding sixth) abdominal segments, inclusive; 2 marginal pairs on anal segment; in all, 16 or 17 pairs present.

*Antenna.*—Slightly flattened; with 2 small, slender, partially invaginated setae.

*Rostralis.*—In one specimen, 2.4 mm long.

*Anal segment.*—Moderately sclerotic mesocaudally; with 6 pairs of setae, 4 pairs being on dorsal surface, 2 of which are mesocephalad in position, and 2 pairs, 1 of which is comparatively large, on or near ventrocaudal margin; anus slightly cephalad of center.

SECOND-STAGE MALE

(Fig. 39, *A–D*)

*Body.*—Elongate elliptical, with sides nearly parallel; the two ends nearly equally rounded; segmentation obscure except for differentiation of posterior end from remainder of body; posterior end not segmented, but apparently composed of three posterior abdominal segments; membranous except for moderate to strong sclerotization of posterior end. Papillae absent. A typical specimen 0.29 mm long and 0.09 mm wide.

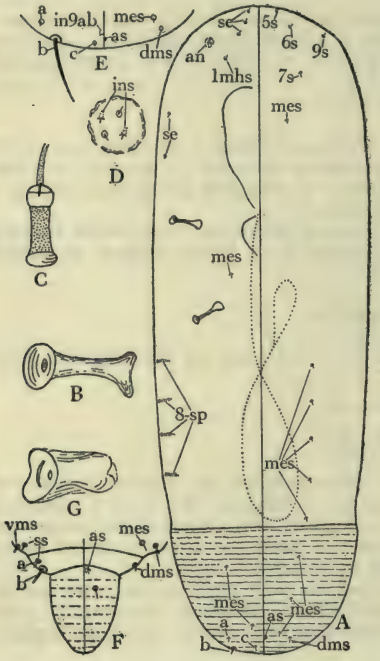


FIGURE 39.—*Halimococcus borassi: A*, Second-stage male, body, dorsal and ventral, × 400; *B*, same, mesothoracic spiracle, × 1,000; *C*, same, marginal pore, × 3,000; *D*, same, antenna, × 2,000; *E*, third-stage male, posterior end, dorsal and ventral, × 400; *F*, fourth-stage male, posterior end, dorsal and ventral, × 400; *G*, same, mesothoracic spiracle, × 1,000.

*Pores.*—Apparently about four pairs of minute 8-shaped pores present along body margin between metathoracic spiracles and sclerotic posterior end. No other pore types present.

*Body setae.*—Subequal; typically with 8 pairs apparently on head; 2 marginal pairs and 1 dorsomesal pair on prothorax, 1 dorsomesal pair each on first to seventh abdominal segments, inclusive, 1 ventromesal pair on mesothorax and 6 pairs on anal segment; in all, 25 pairs present.

*Antenna.*—Essentially as in *Halimococcus lampas*, except possibly with 4 minute setae, 2 being slender and 2 invaginated.

*Rostralis.*—With one elongate caudal loop and the small cephalic loop, when uncoiled within body; in one specimen, 0.63 mm long.

*Legs.*—Not in evidence.

*Anus.*—On dorsal surface near caudal margin.

*Exuviation.*—No data available.

THIRD-STAGE MALE

(Fig. 39, *E*)

Available material too delicate to distinguish the parts satisfactorily except on anal segment; the latter with 5 pairs of setae, 1 pair unusually prominent.

FOURTH-STAGE MALE

(Fig. 39, *F* and *G*)

Available material in condition to distinguish very few structures satisfactorily. Body elongate elliptical, with posterior projection evenly rounded and moderately sclerotic nearly to its base. Spiracularlae inclined to be stout, moderately sclerotic, subequal. Four pairs of setae on or near margin of seventh, and 3 pairs similarly located, 1 of which is comparatively large and spinelike, on eighth abdominal, and 1 dorsomesal pair on anal segment. One specimen 0.22 mm long and 0.07 mm wide.

ADULT MALE

No available material.

### Genus PLATYCOCCUS, new genus

#### First Stage

Body elongate elliptical, distinctly flat in cross section; caudal margin of abdomen without a bulge; segmentation of head, prothorax, and mesothorax obscure, elsewhere more distinct; neither posterior end nor any other part of body derm distinctly sclerotic. 8-shaped pores delicate, elongate; partitions not in evidence through tubes, scarcely so through bars; latter difficult to distinguish apart; bullae distinct, comparatively long; external openings flush with surface; typically 4 pairs present, all dorsomesally situated. A single trilocular pore associated with each mesothoracic spiracle, but no pores associated with metathoracic spiracles. No invaginated tubes connecting tracheae to exterior; spiraculariae elongate, moderately sclerotic, subequal. Clear area laterad of each metathoracic coxa apparently absent. Typically 9 pairs of setae on head, frontal pair between arms of head skeleton being absent, 3 pairs on prothorax, 4 pairs on mesothorax, 5 pairs on metathorax, 1 pair on first abdominal segment, 3 pairs each on second to sixth abdominal segments, inclusive, 4 pairs on seventh, and 5 pairs on posterior abdominal segment. Antenna 6-segmented; basal segment not twice as broad as any other segment; apical segment noticeably elongate. Antennal setae occurring typically as follows: 3 slender setae on basal segment; no setae, but a spinelike process, on second segment; none on third; 1 fleshy seta on fourth; 2 slender setae and 1 fleshy seta on fifth; 2 slender and 5 fleshy setae on apical segment. Rostrum apparently with only 1 pair of setae, this one near apex; rostralis with a single long caudal loop besides the small cephalic loop, when uncoiled within body. Legs distinctly elongate; neither trochanter and femur nor tibia and tarsus fused. Leg setae occurring typically as follows: 4 setae, including minute basal one, on procoxa; 3 setae, including minute basal one, on each of other coxae; 2 setae, including minute basal one and a comparatively long one, on trochanter; none on femur or tibia; 3 setae on tarsus; 2 setae on claw. Anus small and delicate; on ventrocaudal margin; anal ring absent. Male partially puparial.

#### Second-Stage Female

Body elongate elliptical; general outline continued evenly around posterior end, but head characteristically prolonged; markedly flat in cross section; dorsal and ventral surfaces in juxtaposition entirely around for an appreciable distance within margin; segmentation obscure throughout except that of anal valve; membranous in younger individuals except for anal valve. Distinct papillae absent, but in older specimens with shallow dermal thickenings scattered over dorsum. 8-shaped pores present, all minute, comparatively numerous, the majority scattered along margin and submargin of body; partitions obscure both through bars and tubes; bars difficult to distinguish apart; bullae delicate; external openings delicate, flush with surface. In older specimens with distinct channels connecting 8-shaped pores with interior of body. Typically 1 or 2 quinquelocular pores associated with each of 4 spiracles, in slight depressions leading to latter; no other quinquelocular pores on body. All 4 spiracles in shallow depressions, none surrounded by any pronounced sclerotization; spiraculariae elongate, moderately sclerotic, subequal. All body setae minute; at least 5 pairs each on head and seventh abdominal segment, 1 to 3 pairs each apparently on all remaining body segments except anal valve. Antenna on or near margin; limited to a single, relatively small, roundish sclerotic piece, having 2 minute, slender, partially invaginated setae; in older specimens with a channel leading to interior of body. Rostral setae, if present, obscure; rostralis not available. A membranous area, through which rostralis of adult is forced, absent. Anal valve present with characteristic markings; lacking pores but with 4 pairs of setae; anus cephalad in position on anal valve; anal ring apparently absent. Becomes puparium; dorsal derm strongly sclerotic.

#### Adult Female

Body pyriform (inverted); head prolonged as in second-stage female; general outline continued more or less evenly around posterior end; segmentation obscure except on ventral surface of thorax caudad of rostrum and on abdomen; in both young and old specimens derm membranous except for a ridged effect resembling sclerotization on more or less of ventral surface of seventh abdominal segment. Papillae absent except around spiracles; largely spinelike and serrated in appearance. 8-shaped pores small; confined to region between mesothoracic spiracles

and head skeleton and rostrum; moderately numerous; partitions obscure or absent through bars as well as through tubes; bars difficult to distinguish apart; bullae comparatively large, slightly enlarged and thickened through one section; external openings flush with surface and considerably expanded. Quinquelocular pores absent. Both pairs of spiracles flush with surface; spiracullariae moderately elongate, distinctly sclerotic, subequal. Body setae small in general, almost minute, and subequal except on anal segment; typically 7 pairs on head, 9 pairs on thorax, and 31 pairs on abdomen. Antenna essentially as in second-stage female; limited to a single sclerotic piece having one pair of minute partially invaginated setae. Rostral setae obscure; no available data on rostralis. Anal segment on both surfaces of posterior end; membranous; pores absent; with 4 pairs of setae, 2 pairs on ventrocaudal margin slightly larger than the others. Anus well up on dorsum; moderate in size; anal ring probably absent.

### Second-Stage Male

Body apparently elongate elliptical; segmentation obscure except ventrally on sclerotic abdominal segments; five of latter moderately sclerotic, remainder of body delicately membranous. Papillae absent. 8-shaped pores rather numerous, subequal, restricted to marginal or submarginal regions on the sclerotic posterior end, but scattered elsewhere; partitions apparently extending through bars but not into tubes; bars can be distinguished apart with difficulty; bullae long and delicate; external openings expanded and at apices of sclerotic projections. All other pore types absent. Spiracullariae elongate, moderately sclerotic, subequal. At least 3 pairs of setae on each of the 6 posterior abdominal segments, none dorsomesal in position and all about subequal. Antenna occurring as a distinctly projecting tubercle; with several pairs of small setae only. Anus small; on caudal margin; anal ring absent.

### Adult Male[9]

Body elongate elliptical, with posterior end occurring as a fairly large, moderately slender, rapierlike projection; membranous except for anal segment. Vestiges of thoracic wing framework and wings apparently absent. Spiracullariae expanded at both ends and narrow in middle; not elongate, moderately sclerotic, subequal. Eighth abdominal segment with 4 pairs and anal segment with 3 pairs of setae. Antenna with 2 stocky basal segments and an elongate club having 5 segments more or less compactly joined, of which the apical segment is elongate but not twice the length of any other segment of club; basal antennal segment with 2 slender setae, second segment with none, and each segment of club with 2 or 3 long slender and 3 to 5 long fleshy setae. With a single pair of eyes, marginal in position. A vestige of head skeleton apparently present as a differentiated area on ventromeson; invagination to alimentary tube in evidence. Legs stocky, rather large, and approximately subequal, though metathoracic femora, tibiae, and tarsi appear to be slightly larger than those of the other two pairs; tarsus shorter than tibia; setae either slender and small and few in number, or fleshy, comparatively long, and rather plentiful in number; definite sensory areas on any segment apparently lacking. Anus on or near cephalic border of anal segment.

Type of genus, *Platycoccus tylocephalus*, new species.

### Platycoccus tylocephalus, new species

Material collected in 1920 by L. A. Whitney on "palm", Honolulu, Hawaii. All specimens on green leaves in exposed places.

[9] Available material not in condition for determination of all parts.

### EGG

(Fig. 40, *F*)

Oviparous. With a pair of separate spines along ventromesal line; the cephalic spine usually appearing approximately between the basal antennal segments and slightly smaller than the caudal spine.

### FIRST STAGE

(Fig. 40, *A–E*)

*Body.*—With no clearly defined sclerotic areas near head skeleton. Delicate pair of mesal furcae between mesothorax and metathorax. A typical newly hatched specimen 0.35 mm long and 0.16 mm wide; a typical puparium 0.82 mm long and 0.39 mm wide.

*Pores.*—8-shaped pores subequal. Typically 5 pairs of 8-shaped pores present, all dorsomesally situated as follows: 1 pair on head; 1 pair either on prothorax or on anterior section of mesothorax; 1 pair each on or near suture separating mesothorax from metathorax, and metathorax from first abdominal segment; 1 pair on seventh abdominal segment. The trilocular pore associated with each mesothoracic spiracle prominent; margins slightly indented.

*Spiracles.*—Spiracullariae slender, slightly curving, subequal; mesothoracic pair closely attached to trilocular pores by sclerotic extensions.

*Body setae.*—Typically 9 pairs on head, first 2 ventromesal pairs comparatively long, third ventromesal pair and a dorsomesal pair quite small, fourth ventromesal pair moderately long, 4 remaining pairs moderate in size and all on or near margin; 2 marginal pairs and 1 dorsomesal pair on prothorax; 1 marginal pair on anterior section of mesothorax; 1 marginal, 1 ventromesal, and 1 dorsomesal pair on posterior section of mesothorax; 2 marginal pairs, 1 ventrosubmarginal, 1 ventromesal, and 1 dorsomesal pair on metathorax; 1 dorsomesal pair on first abdominal segment; 2 marginal and 1 ventrosubmarginal pair each on second to sixth abdominal segments, inclusive; 2 marginal, 1 ventrosubmarginal, and 1 ventromesal pair on seventh abdominal segment; 5 pairs on posterior abdominal segment; in all, 46 pairs present. All marginal pairs on thorax and abdomen and both ventromesal pairs on thorax moderate in size; all submarginal and dorsomesal pairs on thorax and abdomen comparatively small. Shafts of all setae on thorax and abdomen, except those of the 2 long caudal pairs, comparatively short. In one specimen, outer and inner long caudal setae 53 and 121 microns long, respectively.

*Antenna.*—Moderately elongate. One distal seta of apical segment long and rather fleshy, the other long and threadlike.

*Rostralis.*—In one typical specimen, 0.68 mm long.

*Legs.*—Elongate. With 2 minute setae, including basal one, and 2 other setae on each procoxa.

*Anal ring.*—Absent.

*Exuviation.*—Rupture in both sexes occurring caudad of antennae, the ventral skin rolling back toward posterior end. In male, the head skeleton and legs come to rest in an inverted position slightly beyond the middle of the body.

*Dried material.*—Pale brown; naked in appearance; flat.

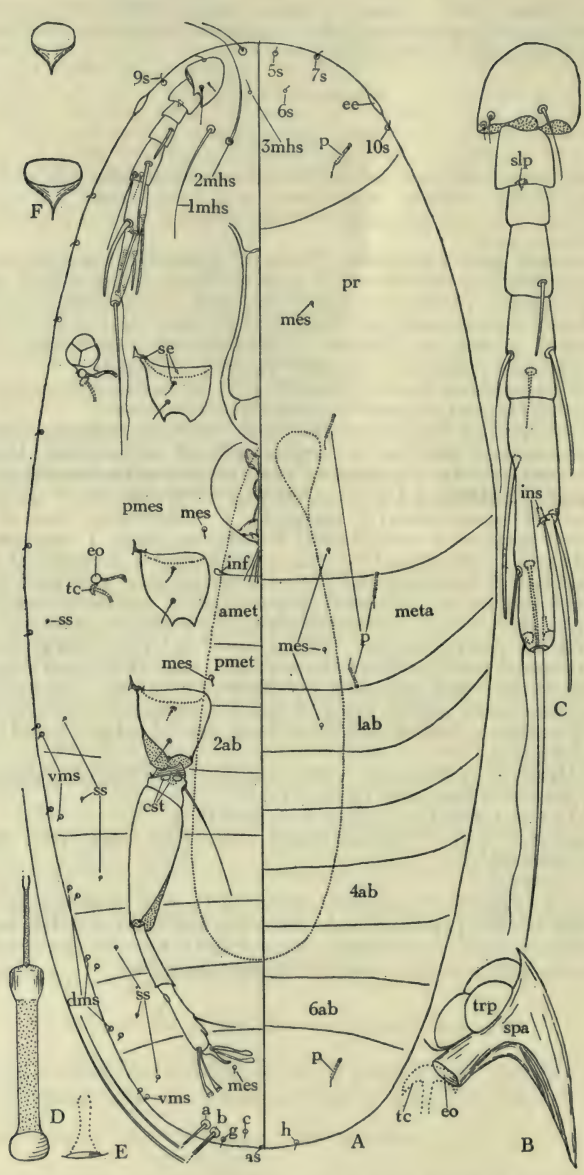


FIGURE 40.—*Platycoccus tylocephalus: A*, First-stage nymph, body, dorsal and ventral, × 400; *B*, same, mesothoracic spiracle, × 2,000; *C*, same, antenna, × 1,000; *D*, same, 8-shaped pore, × 3,000; *E*, same, anus, × 1,500; *F*, egg, pair of spines, in size and distance apart, relatively as shown, × 1,500.

### SECOND-STAGE FEMALE

(Figs. 41 and 42)

*Body.*—A newly molted specimen in good condition was not available. Puparium heavily sclerotic on dorsum, almost membranous on venter. A mem-

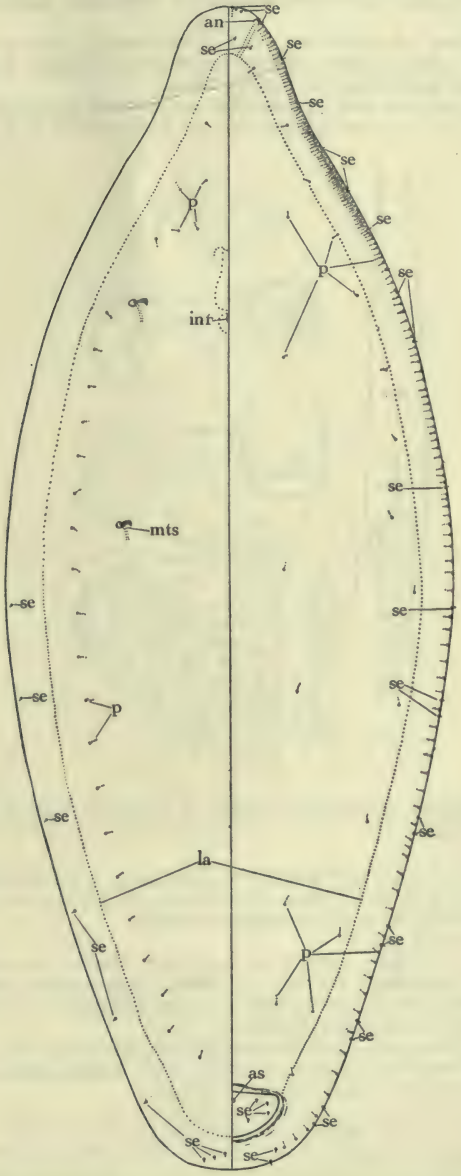


FIGURE 41.—*Platycoccus tylocephalus*, second-stage female: Body (puparium), dorsal and ventral, × 70.

branous area near head skeleton for penetration of adult rostralis lacking, latter being forced through derm near caudal end of a comparatively long rostral slit. A typical puparium 2.2 mm long and 0.8 mm wide.

*Pores.*—8-shaped pores comparatively small; situated ventromesally on head, prothorax, and posterior end, and in distinct rows marginally and submarginally

on both surfaces and dorsomesally on head. The following pores counted in the marginal row on one side of one typical specimen: 1 on head, 109 from antenna to mesothoracic spiracle, 25 between spiracles, and 41 caudad of metathoracic spiracle; on one side of same specimen, 14 dorsosubmarginal, 23 ventrosubmarginal, 6 dorsomesal, and 3 ventromesal ones; in all, 222 present on one side of body. Either 1 or 2 quinquelocular pores associated with each mesothoracic and 1 slightly smaller quinquelocular pore associated with each metathoracic spiracle; all noninvaginated.

*Spiracles.*—Opening into shallow roundish depressions, along with accompanying quinquelocular pores; mesothoracic depressions slightly larger than metathoracic ones; spiraculariae approximately alike.

*Body setae.*—All minute and apparently on or near margin except those on anal valve, as follows: 5 pairs apparently on head; then well spaced, in order,

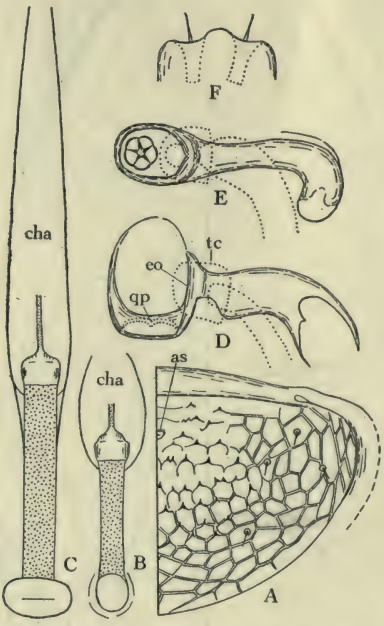


FIGURE 42.—*Platycoccus tylocephalus*, second-stage female: *A*, Anal valve, × 350; *B*, mesal 8-shaped pore, × 3,000; C, marginal 8-shaped pore, × 3,000; *D*, mesothoracic spiracle, × 1,000; *E*, metathoracic spiracle, × 1,000; *F*, antenna, × 2,000.

8 single pairs, 1 set of 2 pairs and 5 sets of 3 pairs each, 1 set of 5 pairs (on seventh abdominal segment); 4 pairs on anal valve; in all, 39 pairs present.

*Antenna.*—Essentially as in *Halimococcus lampas.*

*Rostralis.*—Not available.

*Anal valve.*—In younger specimens covering tissue moderately sclerotic, typically spiny mesocephalad, reticulated laterad and caudad; with four pairs of setae of approximately the same size and situated laterad but away from margin. Anus small; distinctly cephalad in position.

*Dried material.*—Puparium dark brown; naked; decidedly flat but less so than in first stage; dorsal surface sloping gently to meet ventral surface along a sharp line; posterior end pointed nearly straight dorsad.

### THIRD-STAGE FEMALE

Not identified.

ADULT FEMALE

(Figs. 43 and 44)

*Body.*—Segmentation, where obscure, indicated largely by positions of spiracles and setae. A typical specimen 1.3 mm long and 0.56 mm wide.

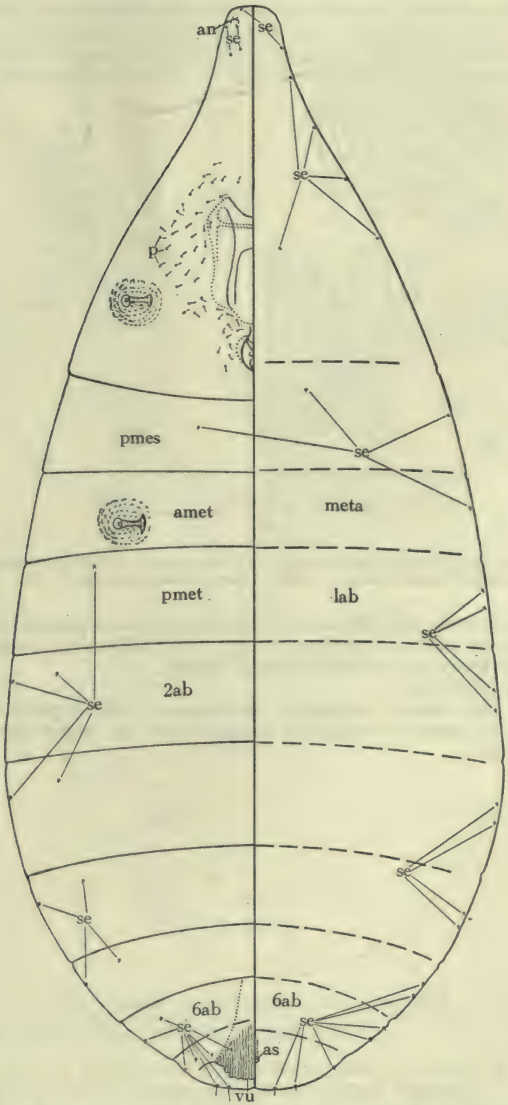


FIGURE 43.—*Platycoccus tylocephalus*, adult female: Body, dorsal and ventral, × 100.

*Pores.*—8-shaped pores distinct though small; irregularly grouped in general region mesad of mesothoracic spiracles on one side and head skeleton and rostrum on other side; 47 counted on one side of one specimen.

*Spiracles.*—Surrounding papillae distinctly sclerotic, either broad and shallow, with distinct serrations, or occurring as small spinelike structures, singly or in groups.

*Body setae.*—All small except on anal segment. Typically with apparently 7 pairs on head; 3 dorsomarginal and 1 dorsomesal pair on prothorax; 1 dorsomarginal, 1 dorsomesal, and 1 ventromesal pair on mesothorax; 1 dorsomarginal and 1 ventrosubmarginal pair on metathorax; 2 dorsomarginal pairs on first abdominal segment; 2 dorsomarginal pairs, 1 ventromarginal, and 1 ventrosubmarginal pair on each of second to seventh abdominal segments, inclusive

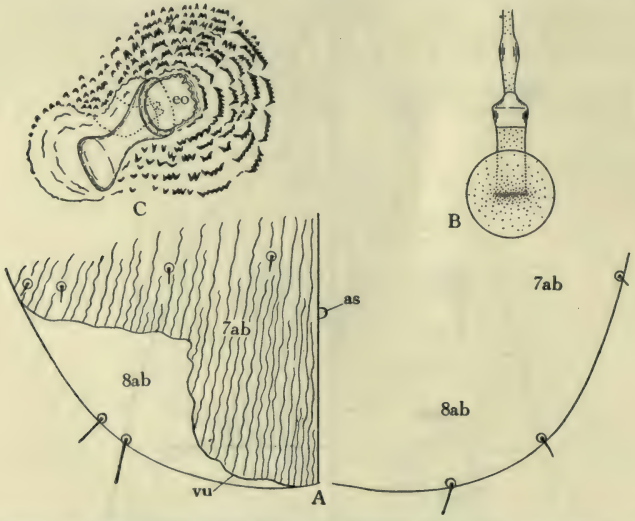


FIGURE 44.—*Platycoccus tylocephalus*, adult female: *A*, Posterior end, dorsal and ventral, × 500; *B*, midventral 8-shaped pore, × 3,000; *C*, metathoracic spiracle, × 500.

and 1 additional ventromesal pair on seventh abdominal segment; 2 dorsomarginal and 2 ventromarginal pairs on anal segment; in all, 47 pairs present.

*Antenna.*—Essentially as in second-stage female.

*Rostralis.*—Not available.

*Anal segment.*—Not clearly delimited on dorsum; with 4 pairs of laterocaudal setae, 2 of which at least are slightly longer than the other body setae; anus cephalad in position.

SECOND-STAGE MALE

(Fig. 45, *A–D*)

*Body.*—Delicate and inclined to wrinkle, except the five posterior abdominal segments; segmentation of latter distinct on venter, elsewhere obscure. One specimen about 0.47 mm long and 0.22 mm wide.

*Pores.*—8-shaped pores scattered in general on all body segments caudad to and including the third abdominal segment, but restricted more or less to marginal and submarginal regions of ventral surface on sclerotic posterior end; at least 85 counted on segments cephalad of third abdominal one, typically about 10 pairs

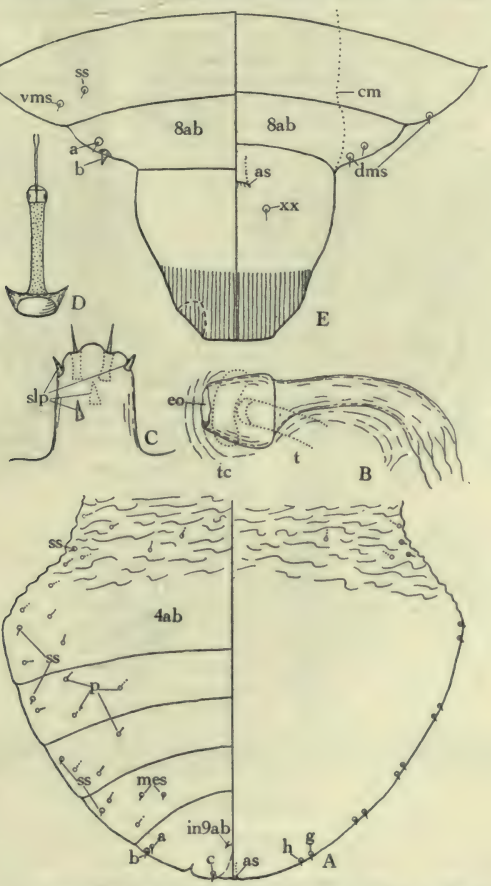


FIGURE 45.—*Platycoccus tytocephalus:* A, Second-stage male, posterior end, dorsal and ventral, × 250; B, same, mesothoracic spiracle, × 1,000; *C*, same, antenna, × 1,500; *D*, same, 8-shaped pore, × 3,000; *E*, fourth-stage male, posterior end, dorsal and ventral, × 400.

on both surfaces of latter, and 2 to 4 pairs each on fourth to seventh abdominal segments, inclusive, and apparently none on anal segment.

*Body setae.*—About 6 sets of at least 2 or 3 pairs each on or near margin cephalad of third abdominal segment, including at least 3 and 2 ventromesal pairs on head and thorax, respectively; 3 pairs each on or near margin of third to seventh abdominal segments, inclusive; 2 ventromesal pairs on seventh abdominal segment; 5 pairs on anal segment.

*Antenna.*—With apparently four minute spinelike setae and a pair of partially invaginated setae.

*Rostralis.*—Not available.

*Legs.*—Obscure.

*Exuviation.*—The anterior derm is pushed back caudad against the five sclerotic posterior abdominal segments.

THIRD AND FOURTH MALE STAGES

(Fig. 45, *E*)

Specimens of both stages at hand, but none in sufficiently good condition to determine adequately many of the parts. Fourth stage with stocky posterior projection having slightly curving sides and a rather truncate, characteristically sclerotic apex; with 3 and 4 pairs of setae, marginal or submarginal in position, on seventh and eighth abdominal segments, respectively, and 1 dorsomesal pair on anal segment; legs sharply elbowed; one specimen 0.60 mm long and 0.28 mm wide.

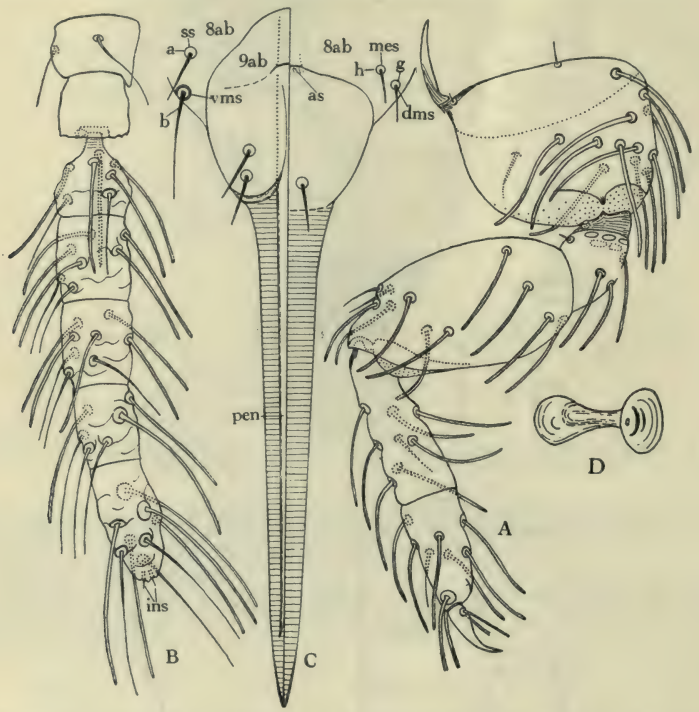


FIGURE 46.—*Platycoccus tylocephalus*, adult male: *A*, Metathoracic leg, × 400; *B*, antenna, × 400; *C*, posterior end, dorsal and ventral, × 400; *D*, mesothoracic spiracle, × 1,000.

ADULT MALE

(Fig. 46)

*Body setae.*—One comparatively large marginal pair on eighth abdominal segment.

*Antenna.*—Segments of club compactly joined; their setae irregularly scattered with typically the following slender and fleshy setae, respectively: First segment 2 and 5, second 2 and 5, third 3 and 5, fourth 3 and 3, fifth 3 and 5.

*Legs.*—Typically with the following number of slender and fleshy setae, respectively, on a metathoracic leg: Coxa 2 and 12, excluding minute basal one; trochanter none and 3, excluding minute basal one; femur 2 and 9; tibia 1 and 7; tarsus 1 and 8; claw 2 rather fleshy setae only.

**Genus THYSANOCOCCUS, new genus**

FIRST STAGE

Body elongate elliptical; margin firm and may be slightly serrated; caudal margin of abdomen without a bulge; segmentation of head, prothorax, mesothorax, and possibly dorsum of posterior abdominal segments ill defined, elsewhere dis-

tinguishable; posterior end not distinctly sclerotic. 8-shaped pores restricted to marginal and mesal regions of dorsum; majority small but some dorsomesal ones may be comparatively prominent; partitions extending hardly through bars or slightly into tubes; bars usually so closely joined as to be difficult to distinguish apart; bullae generally distinct; external openings situated at apices of distinctly sclerotic conical projections; typically 14 to 19 pairs present. A single quinquelocular pore associated with each mesothoracic spiracle, but no pores associated with metathoracic spiracles. Mesothoracic spiracles deeply invaginated, with granulate tubes connecting them to margin of body; quinquelocular pores either practically flush with surface or slightly invaginated, not within invaginated tubes but situated near external openings of latter and body margin; metathoracic spiracles not invaginated; spiracullariae of each pair more or less sclerotic and may or may not be subequal. Clear area laterad of each metathoracic coxa distinct or apparently absent. Typically 10 or 11 pairs of setae on head, frontal pair between arms of head skeleton absent, and first 3 or 4 ventromesal pairs comparatively prominent; 7 to 9 pairs on prothorax and mesothorax together; 4 to 6 pairs on methathorax; 2 pairs on first abdominal segment; 2 to 4 pairs each on second to fifth, inclusive; 2 to 5 pairs each on sixth and seventh; and 6 pairs on posterior abdominal segment. Antenna of the annulated type; 2 to 4 basal segments plainly distinguishable. Antennal setae occurring typically as follows: 2 slender setae, 1 large and 1 small, on basal segment; 1 large slender seta and a spinelike process on second segment; 1 small slender seta on third segment; 7 fleshy and 3 more slender setae on remainder of antenna; in all, 14 antennal setae present. Rostrum with apparently 3 minute pairs of setae, 2 apical and 1 basal in position; rostralis with a single long caudal loop and the small cephalic loop, when uncoiled within body. Legs moderately slender or inclined to be stout; trochanter and femur, and tibia and tarsus, may or may not be fused. Leg setae occurring typically as follows: Either 3 or 4 on each coxa; 2, 1 a minute basal seta and 1 comparatively long, on trochanter; none, 1, or 2 on femurs either none or 1 on tibia; 3 and a spinelike process on tarsus; 2 on claw. Anu; small but distinct; on or near ventrocaudal margin; anal ring apparently may os may not be present; anal-ring setae absent. In all available specimens malr instar partially puparial.

### Second-Stage Female

Body moderately to elongate elliptical; general outline continued more or lesevenly around posterior end; segmentation obscure except ventromesally on abdomen and on both surfaces of the 2 or 3 posterior abdominal segments; in younger specimens moderately sclerotic throughout, including anal valve; margin comeparatively firm or rigid; dorsal and ventral surfaces meet along a distinct more or less fringed line, which, however, may not extend entirely around margin. Papillae may or may not be in evidence. Dorsum with a partial or almost wholly reticulated surface, or lacking reticulations. 8-shaped pores of the ordinary kind only, or both the ordinary and the variating kinds. The ordinary kind of 8-shaped pore small or moderate in size; partition extending through no more than both bars; latter difficult to distinguish apart; bullae delicate and slender, or more pronounced and broad; external openings surrounded by narrow sclerotic rims, but not on distinctly raised projections. 8-shaped pores scarce or, if moderate in number, largely in rows on or near body margin, especially to be noted being a ventrosubmarginal row curving more or less mesad toward both ends of body. Typically none to 2 subequal quinquelocular pores, noninvaginated in themselves, associated with each mesothoracic but not with metathoracic spiracles. A row of quinquelocular pores, singly or in groups of from 2 to 5, may or may not occur along body margin; when present, with typically 19 to 31 pores on each side of body. Mesothoracic spiracles, with associated quinquelocular pores, within deep, more or less granulate invaginated tubes which open on body margin; metathoracic spiracles open on surface; spiracullariae elongate, distinctly sclerotic, subequal or not subequal. A membranous area for pentration of adult rostralis apparently absent. Body setae comparatively few in number, confined almost wholly to ventral surface except on caudolateral surface of abdomen; typically none to 3 pairs on each body segment except anal valve; in all, 19 to 25 pairs present. Antenna limited to a single sclerotic piece having 1 or 2 large fleshy setae and none or 1 minute surface seta, besides the pair of small setae, which may be wholly or partially invaginated. Apparently 1 or 2 pairs of minute, almost indistinct, apically situated rostral setae present; rostralis with 1 elongate loop and the small cephalic loop or, in addition, with 2 large roundish loops, when uncoiled within body. Anal valve present; with or without

characteristic markings; may or may not posses pores; with 4 to 7 pairs of setae. Anus caudally situated; anal ring apparently may or may not be present, if so, insignificant; anal-ring setae apparently may or may not be present, if so, quite minute. Becomes puparium; moderately or heavily sclerotic on dorsum; lightly sclerotic on venter.

### Adult Female

Body moderately or elongate elliptical for the most part, with posterior end projecting slightly; segmentation distinguished on venter caudad of mesothoracic spiracles, and usually on dorsum of the 2 or 3 posterior abdominal segments; membranous except on dorsum of posterior end in both young and older individuals. Papillae practically absent but with numerous irregular rows of small spinelike structures on ventromesal surface of thorax and first 2 or 3 abdominal segments; these hardly more than spicules. 8-shaped pores comparatively small; limited largely to a scattering group on each side of body, either mesad of mesothoracic spiracles or immediately caudad of metathoracic spiracles; partitions extending no more than through bars, which may or may not be difficult to distinguish apart; bullae delicate; external openings may or may not be at apices of sclerotic projections; typically from 4 to 35 present in the group on each side of body. Quinquelocular pores absent. Spiracles flush with surface or in shallow depressions; spiracullariae moderately stout or elongate, strongly sclerotic, subequal or not subequal. Body setae moderately pronounced; absent on dorsum except for none to 2 pairs on head and a single marginal pair each on 1 to 4 of posterior abdominal segments, excluding anal one; on venter, typically none or 1 pair on head, 4 to 6 pairs on thorax, and 13 to 16 pairs on abdomen caudad to and including seventh segment. Antenna essentially as in second-stage female. Rostrum with apparently 1 or 2 pairs of minute more or less apical setae; rostralis with 1 elongate loop and the small cephalic loop or, in addition, with 2 large roundish loops, when uncoiled within body (data not available for one species). Anal segment situated on both surfaces; mostly distinctly sclerotic; with from 2 to 6 pairs of small pores. Delicate plates or squamulae projecting from laterocaudal margin of anal segment may or may not be present; if present, varying somewhat in number, size, form, and position, apparently may possess very delicate and elongate pores. Anal segment with from 4 to 6 pairs of small subequal setae. Anus distinct; apparently with anal ring; apparently 1 pair of minute anal-ring setae may or may not be present.

### Second-Stage Male [10]

Body moderately elliptical; segmentation obscure except on ventral surface caudad of metathoracic spiracles; faintly sclerotic throughout, anal segment a little more so than elsewhere. Papillae absent. 8-shaped pores restricted to marginal or submarginal regions of ventral surface; few in number and comparatively small; no partitions apparent through bars; bars difficult to distinguish apart; bullae broad, but delicate; external openings apparently flush with surface but surrounded by sclerotic rims. The asymmetrical type of tubular pore present; restricted to margin and submargin of ventral surface; fairly numerous and prominent; in structure, bar pronounced but slender, external opening moderately expanded and not on a projection but surrounded by a prominent sclerotic rim having an irregular outer border. Quinquelocular pores absent. Spiracullariae distinctly elongate, moderately sclerotic, mesothoracic pair slightly larger than metathoracic pair. Typically with 1 or 2 marginal or submarginal pairs of setae on venter of each body segment except anterior section of mesothorax, which lacks setae, and anal segment, which possesses 5 pairs; with 3 or 4 pairs each of ventromesal and dorsomarginal setae; with about 9 pairs of dorsomesal setae; all body setae subequal except 1 pair on anal segment. Antenna occurring as a rounded tubercle, with 1 prominent fleshy seta and several minute setae. Rostral setae obscure; rostralis with 1 elongate loop and the characteristic small cephalic loop, when uncoiled within body. Vestigial legs may be in evidence. Anus small, near dorsocaudal margin; anal ring apparently absent.

[10] Data available from one species only.

### Adult Male [11]

Body elongate elliptical, with posterior end occurring as a fairly large, moderately slender rapierlike projection. Vestiges of thoracic wing framework and wings apparently absent. Spiraculariae rather elongate, moderately sclerotic, subequal. Three pairs of setae on eighth abdominal segment and 4 pairs on anal segment. Antenna appreciably elongate; with 2 subequal stocky basal segments and a club with 8 segments, the apical one elongate and twice the length of some, but not of all, the other club segments; first basal segment with 2, second with 3, rather small slender setae, and each segment of club with from 4 to 6 rather fleshy, mostly moderate-sized setae; the 2 basal antennal segments bare of spicules, but each segment of club with numerous whorls of them. With 2 pairs of eyes, 1 marginal in position, the other, distinctly smaller, located on ventral surface. Apparently a vestige of head skeleton occurring as a differentiated area on ventromeson; invagination to alimentary tube in evidence. Rostrum apparently absent. Metathoracic legs moderately larger than mesothoracic pair, which in turn are slightly larger than prothoracic legs; tibiae of all 3 pairs distinctly longer than tarsi, tibiae and tarsi rather stocky, each with a fair number of rather long, slender, irregularly scattered, spinelike setae and a number of whorls of spicules; latter apparently scarce if not practically absent from the other segments; apparently no definite sensory areas present on any segment.

Type of genus, *Thysanococcus chinensis*, new species.

### Keys to Species of Thysanococcus

#### FIRST STAGE

a. Dorsomarginal setae present on third to sixth abdominal segments, inclusive; the 4 basal antennal segments rather clearly defined, with remainder of antenna strongly annulated; no setae on femur or tibia.
  b. With 1 pair of dorsomesal 8-shaped pores on caudal margin of head and on dorsum of each of first and seventh abdominal segments distinctly larger than other 8-shaped pores; mesothoracic quinquelocular pores situated immediately dorsad of external openings of invaginated tubes leading to spiracles; with spiracular invaginated tubes gently curving; with only one row of ventromarginal or submarginal setae on abdomen. **chinensis, new species.**
  bb. All 8-shaped pores subequal; mesothoracic quinquelocular pores located cephalad of external openings of invaginated tubes leading to spiracles; with spiracular invaginated tubes practically straight; with two rows of ventromarginal or submarginal setae on abdomen.
    c. Mesothoracic quinquelocular pores moderate in size, with even margins; spiracular invaginated tubes comparatively broad throughout; with a conspicuous broad rounded granulate area on body margin immediately dorsad of each spiracular invaginated tube; trochanter and femur and also tibia and tarsus of each leg fused---------- **squamulatus, new species.**
    cc. Mesothoracic quinquelocular pores comparatively large, with distinctly indented margins; spiracular invaginated tubes more or less club-shaped; no distinct differentiated area near each spiracle; no leg segments fused---------- **calami, new species.**
aa. Dorsomarginal setae absent on third to sixth abdominal segments, inclusive; only 2 basal antennal segments clearly defined, remainder of antenna weakly annulated; usually with 2 pairs and always with at least 1 pair of setae on each femur and usually 1 pair on each tibia. **pandani, new species.**

#### SECOND-STAGE FEMALE

a. Dorsum largely covered with a number of scattered, distinct, mostly blunt papillae; antenna with two comparatively prominent fleshy setae. **chinensis, new species.**
aa. Dorsum without papillae or other sculpturing, or covered either largely with pronounced reticulations alone or partly with reticulations and partly with spiny areas; antenna with only one comparatively prominent fleshy seta.

[11] Available material not in condition to furnish full data for any species.

b. Dorsum with reticulations only; with a row of 8-shaped pores having single bars with flaring or folded-up sides, and bars, tubes, and bullae about equally sclerotic, along body margin; marginal quinquelocular pores absent---------- **squamulatus**, new species.

bb. Dorsum with reticulations and spiny areas or without any noticeable configurations; no 8-shaped pores as described above; marginal quinquelocular pores present.

c. Dorsum with reticulations and a large reniform area in center of each side covered with long, curving, strongly sclerotic spines; body margin nearly even all around; all setae of anal segment no more than moderate in size---------- **pandani**, new species.

cc. Dorsum without any particular sculpturing; body margin with irregular pronounced indentations; anal segment with one pair of unusually prominent setae---------- **calami**, new species.

ADULT FEMALE

**a**. 8-shaped pores confined largely to a cluster on each side of body caudad of metathoracic spiracles; no forked setae on anal segment.

b. 8-shaped pore cluster on posterior section of metathorax and second and third abdominal segments; antenna with two comparatively prominent fleshy setae---------- **chinensis**, new species.

bb. 8-shaped pore cluster not reaching to third abdominal segment; antenna with only one comparatively prominent fleshy seta.

c. 8-shaped pore cluster practically limited to posterior section of metathorax; from 4 to 12 8-shaped pores in the cluster on each side of body; with marginal plates or squamulae on anal segment. **squamulatus**, new species.

cc. 8-shaped pore cluster on posterior section of metathorax and second abdominal segment; typically with more than 20 8-shaped pores in the cluster on each side of body; anal segment without plates or squamulae---------- **calami**, new species.

**aa**. 8-shaped pore cluster situated mesad of mesothoracic and cephalad of metathoracic spiracles; marginal setae on anal segment typically forked. **pandani**, new species.

THYSANOCOCCUS CHINENSIS, new species

Material from E. O. Essig, collected at Yenping, China, in 1925, exposed on pinnae of *Calamus* sp.

EGG

Not identified.

FIRST STAGE

(Figs. 47 and 52, *B*)

*Body.*—Entire margin slightly serrated; segmentation of head, thorax, and posterior abdominal segments ill defined. Delicate pair of furcae on venter between mesothorax and metathorax. Distinct clear area laterad of each metathoracic coxa. A typical newly hatched specimen 0.32 mm long and 0.15 mm wide; a fully developed female 0.47 mm long and 0.25 mm wide.

*Pores.*—8-shaped pores differing in size; partitions apparently extending very slightly into tubes; bars difficult to distinguish apart; bullae distinct. Typically 2 marginal pairs of 8-shaped pores on head caudad of eyes; 1 marginal pair each on posterior section of mesothorax, metathorax, and second to sixth abdominal segments, inclusive; 1 comparatively large dorsomesal pair on or near suture between head and prothorax; 1 dorsomesal pair each near caudal margin of posterior section of mesothorax and metathorax; 1 comparatively large dorsomesal pair situated slightly laterad on each of first and seventh abdominal segments; in all, 14 pairs present. One moderate-sized quinquelocular pore, very slightly if at all invaginated, present immediately dorsad of external opening of invaginated tube of each mesothoracic spiracle.

*Spiracles.*—Mesothoracic tubes connecting spiracles to exterior long, usually gently curving, and with external openings of tubes on distinct marginal protuberances; spiraculariae elongate, distinctly sclerotic, subequal. No definite differentiated area along margin in neighborhood of mesothoracic invaginated tubes.

*Body setae.*—Typically 6 marginal, 4 ventromesal, and 1 dorsomesal pair on head; 9 marginal, 3 dorsomesal, and 2 prominent ventromesal pairs on thorax; 1 marginal and 1 mesal pair each on dorsum of first to seventh abdominal segments, inclusive; 1 ventrosubmarginal pair each on second to seventh abdominal segments, inclusive; 1 ventromesal pair on seventh abdominal segment; 6 pairs on posterior abdominal segment; in all, 52 pairs present. One marginal pair each on metathorax and posterior segment of abdomen; all ventrosubmarginal and ventromesal abdominal pairs very small. In one specimen, outer and inner long caudal setae 41 and 156 microns long, respectively.

*Antenna.*—With two relatively prominent basal segments, next two small but rather well defined, fifth segment ill defined, remainder of antenna sharply annulated.

*Rostralis.*—In one typical specimen, 0.73 mm long.

*Legs.*—Neither trochanter and femur nor tibia and tarsus fused; femur moderately stout; tarsus rather short. With 4 setae, including minute basal one, on each coxa; no seta on femur or tibia.

*Anal ring.*—May be present; if so, narrow and insignificant.

*Exuviation.*—In female the split occurring submarginally on ventral surface caudad of antennae; usually 1 or 2 pairs of legs pushed back toward posterior end, head skeleton and 1 pair of legs, apparently the metathoracic ones, remaining undisturbed.

*Dried material.*—New individuals decidedly flat, light or pale brown; old ones not so flat, dark brown; both distinctly oval; upper and lower surfaces meeting in sharp line; dorsomedian line carinate; naked in appearance.

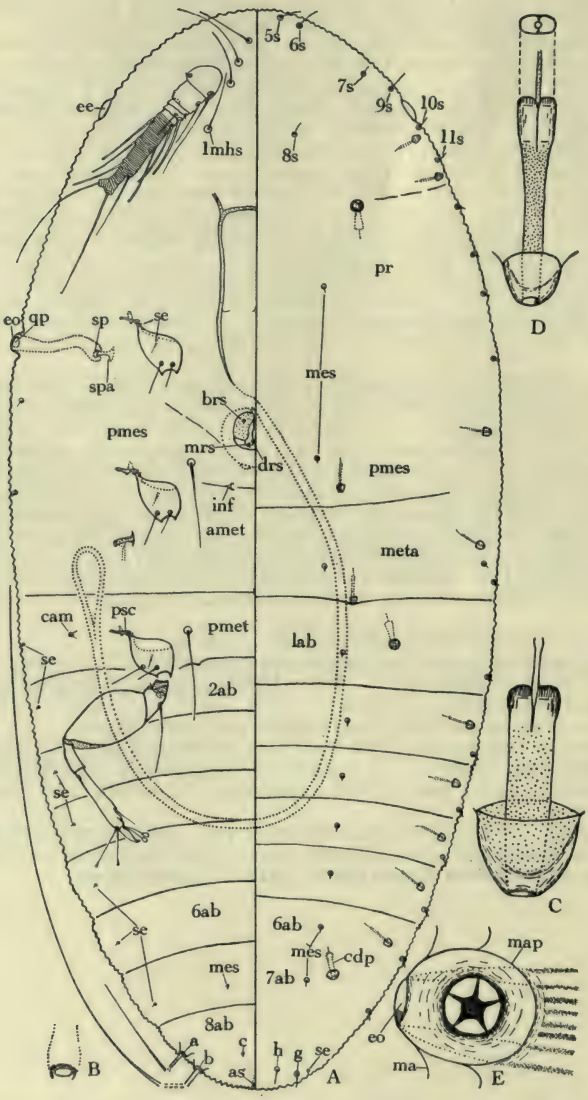


FIGURE 47.—*Thysanococcus chinensis*, first-stage nymph: *A*, Body, dorsal and ventral, × 450; *B*, anus, × 1,500; *C*, caudodorsal 8-shaped pore, × 3,000; *D*, marginal 8-shaped pore, × 3,000; *E*, mesothoracic quinquelocular pore, dorsal, × 2,000.

SECOND-STAGE FEMALE

(Figs. 48 and 49)

*Body.*—Moderately elliptical; slightly more sharply curved along cephalic than along caudal margin. Marginal fringe distinct; extending entirely around mar-

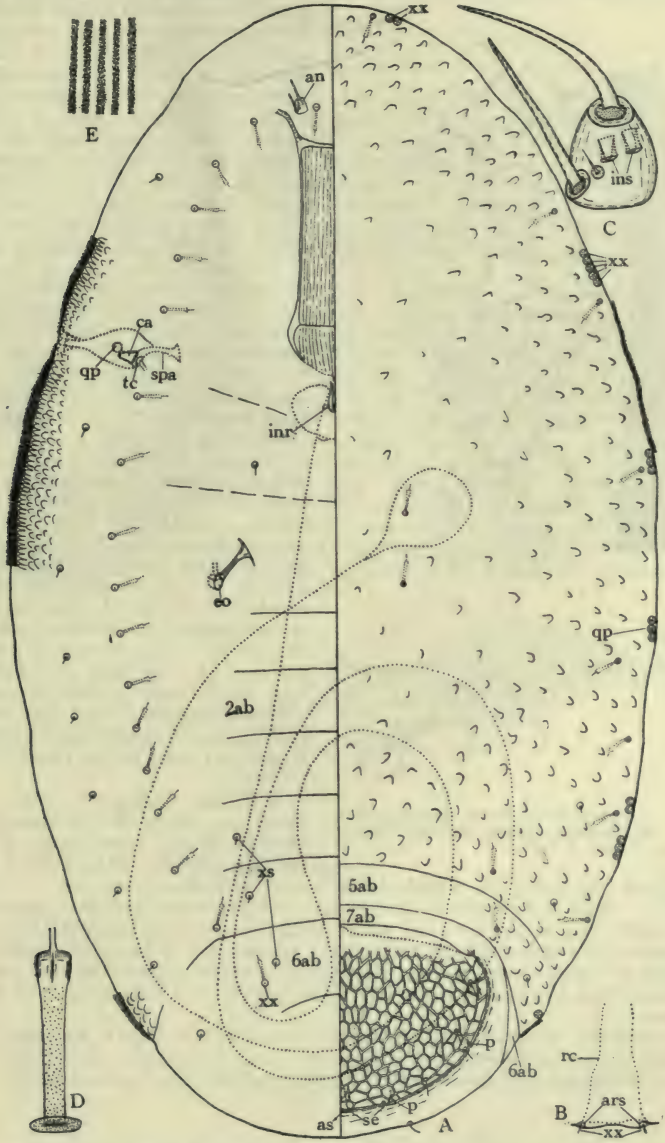


FIGURE 48.—*Thysanococcus chinensis*, second-stage female: *A*, Body, dorsal and ventral (marginal fringe indicated only in sections), × 350; *B*, anus, × 1,500; *C*, antenna, × 2,000; *D*, submarginal 8-shaped pore, × 3,000; *E*, looking down on fringe, × 1,500.

gin except on sixth and seventh abdominal segments; more pronounced ventrally than dorsally; occurring in about five parallel bands, appearing granular when one is looking straight down, or like a stiff brush of cilia when viewed laterally. Ventromarginal surface thickly covered with characteristic laterally directed,

stout, blunt papillae, which end rather abruptly submarginally; entire dorsal surface with a number of scattered distinct, blunt papillae, less numerous mesally in central region of body than along margin. Puparium moderately sclerotic on dorsum. A typical newly molted specimen 0.42 mm long and 0.23 mm wide; a puparium 0.52 mm long and 0.35 mm wide.

*Pores.*—8-shaped pores moderate in size; of the ordinary kind only; occurring singly and spaced rather regularly in rows, marginally on dorsum and submarginally on venter; bullae delicate; external openings delicate and flush with surface; a typical specimen having on one side of body 8 dorsomarginal, 4 dorsomesal, and 18 ventrosubmarginal pores. Typically with 1 quinquelocular pore associated with each mesothoracic spiracle. Typically with from 6 to 8 groups of quinquelocular pores of from 1 to 5 in each group along body margin; groups not always clearly defined; 19 pores on one side of one specimen.

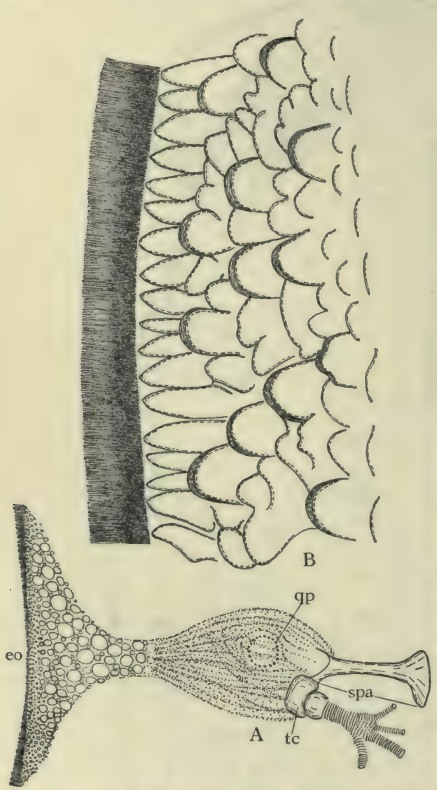


FIGURE 49.—*Thysanococcus chinensis*, second-stage female: *A*, Mesothoracic spiracle, × 1,000; *B*, marginal fringe, ventral, × 2,000.

*Spiracles.*—Invaginated tubes leading to mesothoracic spiracles bulbous mesally, somewhat constricted toward margin, against which they broadly expand; mesal part of tubes faintly granulate, remainder coarsely granulate; an irregularly formed clear area sometimes observed in bulbous part of a tube, possibly an opening into latter; spiracularlae subequal.

*Body setae.*—Comparatively prominent. Apparently none on head; 1 ventrosubmarginal pair each between antennae and mesothoracic spiracles and on the 8 consecutive segments caudad of latter; 1 pair on or near caudal margin of seventh abdominal segment; 1 ventromesal pair near rostrum and on each of fourth, fifth, and sixth abdominal segments; 1 dorsosubmarginal pair each on third, fourth, and fifth abdominal segments; 6 pairs on anal valve; in all, 23 pairs present.

*Antenna.*—Typically with a comparatively large fleshy apical seta, a smaller fleshy basal seta, 1 minute slender surface seta, and 1 pair of small, almost but not quite wholly invaginated, spinelike setae.

*Rostralis.*—With 1 elongate loop, 2 large roundish loops, and the characteristic small cephalic loop, when uncoiled within body; in one specimen, 2.3 mm long.

*Anal valve.*—Covering tissue reticulate; apparently 2 pairs of minute pores and 6 pairs of setae along caudal and lateral margins; anus distinct, on caudal margin; anal ring, if present, narrow; apparently a very minute pair of anal-ring setae present.

*Dried material.*—Puparium dull black above, rich brown around margin, naked, slightly dome-shaped; derm sloping evenly to margin, dorsal and ventral surfaces meeting along a sharp line; posterior end pointed dorsocaudad.

### THIRD-STAGE FEMALE

(Fig. 50, *D*)

Distinct; moderately elliptical; derm membranous. With about 7 pairs of strongly sclerotic blunt tubercles spaced rather regularly around margin; their number and positions varying to some extent; an occasional one present elsewhere on body.

### ADULT FEMALE

(Fig. 50, *A–C*)

*Body.*—Moderately elliptical, with posterior end projecting slightly and broadly. Dorsal sclerotization of posterior end covering anal segment and apparently at least part of mesal region of seventh abdominal segment. A typical specimen 0.48 mm long and 0.32 mm wide.

*Pores.*—8-shaped pores mostly restricted to a loose cluster on each side of body on three segments immediately caudad of metathoracic spiracles; partitions extending only through both bars; bars rather easily distinguished apart; external openings at apices of sclerotic projections; typically about 27 present in the cluster on each side of body.

*Spiracles.*—Spiraculariae rather elongate, subequal.

*Body setae.*—Typically 1 pair on head; 2 pairs each on posterior section of mesothorax and anterior section of metathorax; 1 pair on posterior section of metathorax; 3 pairs each on second and third abdominal segments; 4 pairs each on fourth, fifth, and sixth abdominal segments; 1 pair on seventh and 6 pairs on anal segment; in all, 31 pairs present; 1 or all 3 dorsomarginal pairs on the posterior segments and 1 or 2 ventromesal pairs on abdomen may be absent.

*Antennae.*—Essentially as in second-stage female, that is, with 2 prominent fleshy setae, a minute seta, and 2 small invaginated setae.

*Rostralis.*—With 1 elongate loop, 2 large round loops, and the small cephalic loop, when uncoiled within body; in one typical specimen, 2.8 mm long.

*Anal segment.*—Caudal margin nearly smooth; typically with four 8-shaped pores and 5 pairs of subequal setae along laterocaudal margin; anus centrally located; with apparently a small anal ring and 1 minute pair of anal-ring setae.

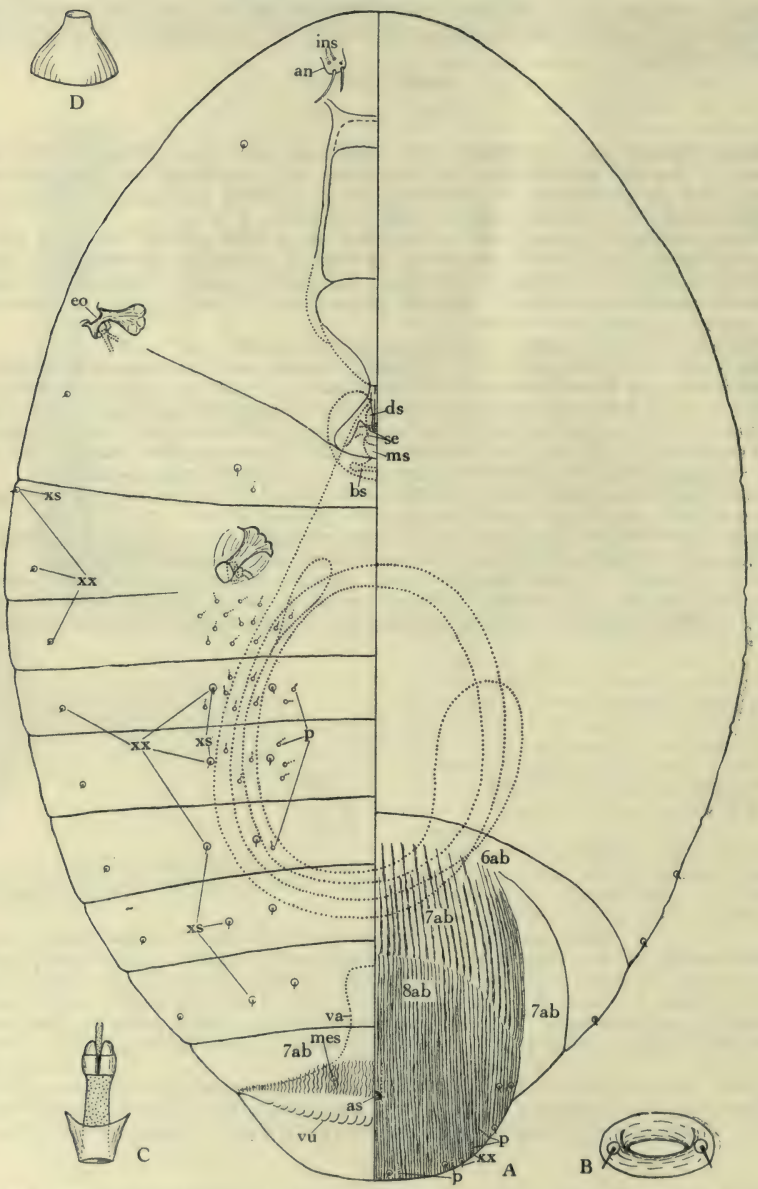


FIGURE 50.—*Thysanococcus chinensis: A*, Adult female, body, dorsal and ventral, × 300; *B*, same, anal ring, × 1,500; *C*, same, midventral 8-shaped pore, × 3,000; *D*, third-stage female, marginal tubercle, × 1,500.

MALE STAGES

Not available.

THYSANOCOCCUS PANDANI, new species [12]

Material from E. E. Green, from Buitenzorg, Java; C. L. Marlatt and A. Zimmermann on *Pandanus* sp., United States Bureau of Entomology; 2 lots from Buitenzorg, Java, 1 on *Pandanus* sp. (1901) collected by C. L. Marlatt, the other on *Pandanus tectorius*, received

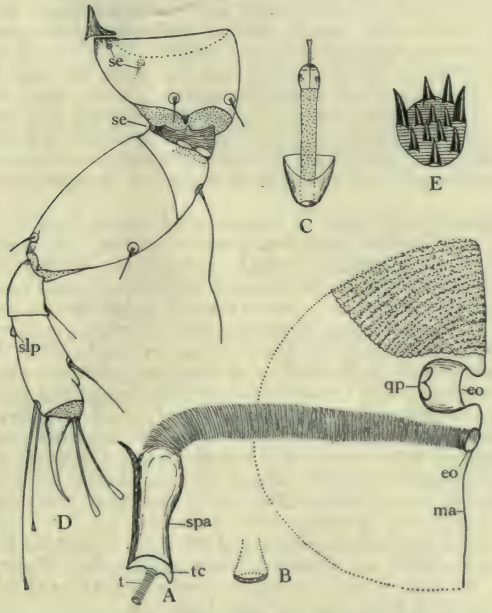


FIGURE 51.—*Thysanococcus pandani: A*, First-stage nymph, mesothoracic spiracle, showing full outline, but details of only a portion of dorsal sclerotic area, × 2,000; *B*, same, anus, × 1,500; *C*, same, 8-shaped pore, × 3,000; *D*, same, metathoracic leg, × 1,000; *E*, egg, spine group, × 1,500.

at quarantine, Washington, D.C., in 1920, collected by W. S. Fisher, United States Bureau of Entomology, 2 lots from Botanic Gardens, Singapore, 1 on *Pandanus utilis* (1917), the other on *Pandanus penangensis* (1917), both collected by C. F. Baker. Specimens in all these lots were exposed either on leaves or on what appeared to be the fruit.

EGG

(Fig. 51, *E*)

Oviparous. With a group of 8 to 12 spines, moderately spaced and varying distinctly in size of groups and of individual spines; sclerotic body derm extending appreciably around spines.

[12] The specific name is taken from the record one originally assigned to this insect by E. E. Green.

FIRST STAGE

(Figs. 51, *A–D*, and 52, *A*)

*Body.*—Margin serrated, but less so than in *Thysanococcus chinensis;* segmentation of head, prothorax, and mesothorax ill defined, elsewhere more distinct. Clear area laterad of each metathoracic leg apparently present but delicate. A typical newly hatched specimen 0.32 mm long and 0.19 mm wide; a fully developed female 0.57 mm long and 0.37 mm wide; male puparium typically 0.53 mm long and 0.29 mm wide.

*Pores.*—All 8-shaped pores approximately alike in size but comparatively small; partitions distinguishable through bars but apparently absent from tubes; bars difficult to distinguish apart; bullae delicate. 8-shaped pores differing from those of *Thysanococcus chinensis* as follows: 1 of the 2 marginal pairs on head located cephalad of eyes; 3 marginal pairs on thorax; 2 marginal pairs apparently on first abdominal segment; second, third, and fourth abdominal segments usually, though not always, without a marginal pair each; 1 dorsomesal pair on second but not on first abdominal segment; in all, 15 8-shaped pores present. The quinquelocular pore associated with each mesothoracic spiracle of moderate size, slightly invaginated, and situated cephalad of invaginated tube leading to spiracle.

*Spiracles.*—External openings of invaginated tubes leading to mesothoracic spiracles distinct, and not on marginal protuberances. Invaginated tubes relatively straight over their greater length, apparently faintly ridged. A rather large usually sub-semicircular granulate area bordering dorsal margin immediately dorsad of each invaginated tube. Mesothoracic spiraculariae frequently pointed caudocephalad; both pairs elongate, moderately sclerotic, subequal.

*Body setae.*—Essentially as in *Thysanococcus chinensis*, with the following typical variations: Apparently 6 instead of 9 marginal pairs on segments of thorax; apparently no marginal pairs on second to sixth abdominal segments, inclusive; no dorsomesal pair on seventh abdominal segment; in all, 43 pairs present. In one specimen outer and inner long caudal setae 31 and 43 microns long, respectively.

*Antenna.*—Differing from that of *Thysanococcus chinensis* chiefly in having only the two basal segments well defined and in having fewer and less distinct annulations on apical part; setae differing in size and position, but all readily homologized with those of *Thysanococcus chinensis.*

*Rostralis.*—In three typical specimens, 0.46, 0.48, and 0.49 mm long.

*Legs.*—Relatively stout; no fusion of any segments. Four setae, including minute basal one, on each coxa; 2 setae on femur; 1 seta in tibia. One seta each on coxa, femur, and tibia sometimes absent from leg.

*Anal ring.*—Essentially as in *Thysanococcus chinensis.*

*Exuviation.*—In both sexes head skeleton and rostrum drop down caudad; usually observed in an inverted position; ventral skin does not roll back, but remains in position and splits on ventrosubmarginal surface; subsequent male instars may or may not remain within skin. In female second instar normally remains within first-stage skin, and with increasing rotundity merely lifts up dorsal part of skin.

*Dried material.*—Similar to that of *Thysanococcus chinensis* except for a narrow fringe of wax frequently observable around margins.

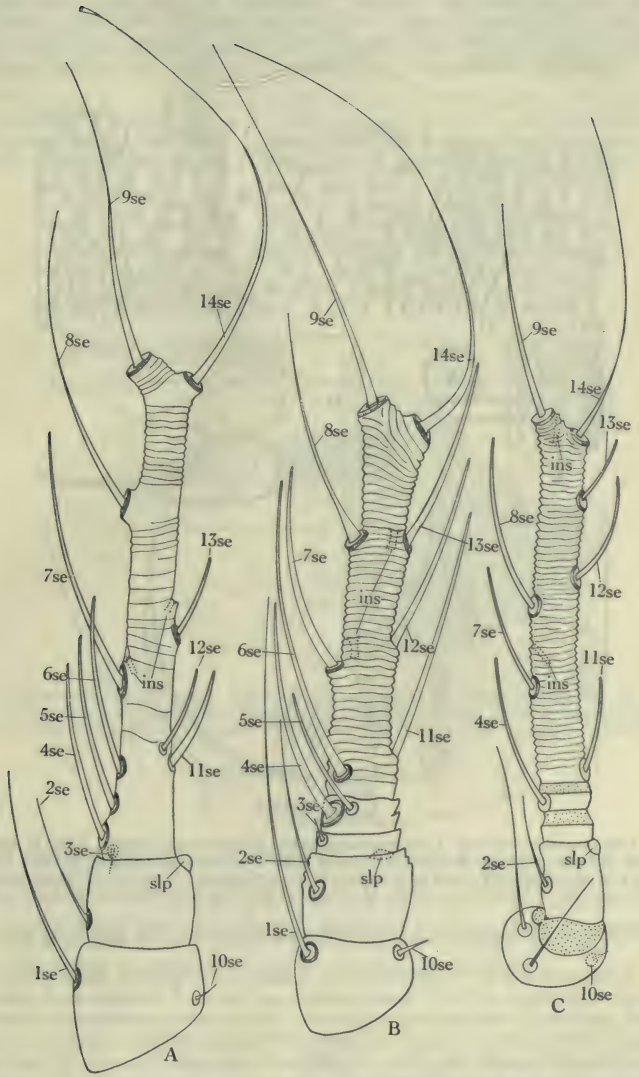


FIGURE 52.—Antennae of first-stage nymphs; *A, Thysanococcus pandani; B, T. chinensis; C, Aspidiotus* sp. × 1,500.

SECOND-STAGE FEMALE

(Fig. 53, *A–G*)

*Body.*—Moderately elliptical, with caudolateral margins very slightly concave in both young and old specimens. Marginal fringe distinctly less pronounced than in *Thysanococcus chinensis*, appearing hardly more than as fine granulations. Ventral submarginal surface coarsely granulate in irregular connected chains; dorsal surface reticulated around margins and mesally, leaving a central somewhat reniform area on each side, covered with long, slender, curving sclerotic projections. Puparium moderately sclerotic on dorsum. A typical newly molted

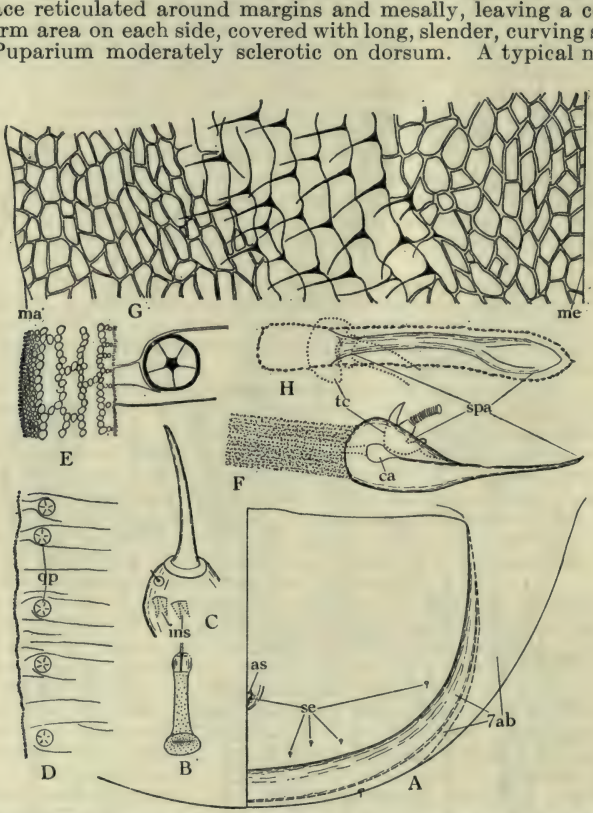


FIGURE 53.—*Thysanococcus pandani: A*, Second-stage female, posterior end, dorsal, × 500; *B*, same, 8-shaped pore, × 3,000; *C*, same, antenna, × 2,000; *D*, *E*, same, fringe, ventral; *D*, × 550, *E*, × 2,000; *F*, same, mesothoracic spiracle, showing only basal part of granulate invagination, × 1,000; *G*, same, section through dorsum, from margin to mesal line, × 500; *H*, second-stage male, mesothoracic spiracle, × 1,000.

specimen 0.46 mm long and 0.28 mm wide; a puparium 0.54 mm long and 0.33 mm wide.

*Pores.*—8-shaped pores comparatively small; of ordinary kind only; one side of a typical specimen with 2 mesal pairs on head, 1 dorsomesal pair each on fourth, fifth, and sixth abdominal segments, 13 ventrosubmarginal pairs relatively evenly spaced from head to and including sixth abdominal segment, and 2 more or less ventromesal pairs on sixth abdominal segment; in all, 20 pairs present. No quinquelocular pores associated with spiracles. On one side of a typical specimen 22 quinquelocular pores counted along margin from and including head to and including sixth abdominal segment; usually occurring singly, sometimes in pairs; rather evenly spaced.

*Spiracles.*—Invaginated tubes of mesothoracic spiracles extending relatively straight from latter to near body margin, against which they broadly expand; tubes finely granulate near spiracles, but coarsely granulate in their expansions near body margin, which is distinctly indented here. Mesothoracic spiraculariae larger than metathoracic pair; both pairs tapering mesally and bulbous around spiracles.

*Body setae.*—Essentially as in *Thysanococcus chinensis* except smaller, and ventromesal pair apparently absent from fourth abdominal segment; ventrosubmarginal setae interspersed with 8-shaped pores of this region.

*Antenna.*—Essentially as in *Thysanococcus chinensis* except for absence of the basal fleshy seta.

*Rostralis.*—With one elongate loop and the characteristic small cephalic loop, when uncoiled within body; in one specimen, 0.99 mm long.

*Anal valve.*—Covering tissue distinctly sclerotic, with markings obscure; pores apparently absent; with four minute pairs of setae near laterocaudal margins; anus small but with some thickened tissue around it; anal ring probably present; apparently with a pair of minute anal-ring setae.

*Dried material.*—Puparium dark brown at first, turning rather shiny black later; naked except for a fringe of whitish wax usually around margins; dorsum dome-shaped, sloping evenly to margin, the two surfaces meeting in a sharp line; posterior end pointed straight dorsad; first-stage exuvia covering dorsal surface.

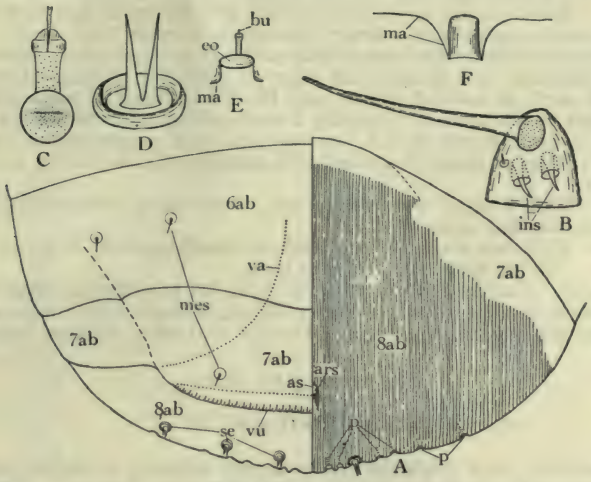


FIGURE 54.—*Thysanococcus pandani: A*, Adult female, posterior end, dorsal and ventral, × 500; *B*, same, antenna, × 2,000; *C*, same, midventral 8-shaped pore, × 3,000; *D*, same, posterior marginal seta, × 3,000; *E*, same, posterior marginal 8-shaped pore, × 3,000; *F*, third-stage female, marginal tubercle, × 1,500.

### THIRD-STAGE FEMALE

(Fig. 54, *F*)

Distinct; body moderately elliptical; derm membranous. A row of tubercles around margin, distributed much as in *Thysanococcus chinensis*, but in structure blunter, more or less cylindrical, and typically in pronounced depressions of body derm; 35 counted on one side of one specimen. Thin spots to accommodate 8-shaped pores of preceding instar present along ventrosubmargin. A pair of delicate spots on head, possibly extreme vestiges of antennae.

### ADULT FEMALE

(Fig. 54, *A–E*)

*Body.*—Moderately elliptical, with posterior end projecting less than in *Thysanococcus chinensis;* segmentation on dorsum obscure, even that between seventh abdominal and anal segments; typically a pronounced suture or depression extending from meson immediately caudad of rostrum toward each mesothoracic spiracle. Dorsal sclerotization of posterior end apparently covering anal segment and much of seventh abdominal segment; indistinctly defined along its cephalic border. A typical specimen 0.48 mm long and 0.28 mm wide.

*Pores.*—8-shaped pores confined largely to region between mesothoracic spiracles and head skeleton; a pair usually present immediately cephalad of metathoracic spiracles; partitions apparently extending through both bars; bars distinguished apart with difficulty; external openings not on sclerotic projections, flush with surface, and much expanded; 22 counted in the cluster on one side of one specimen.

*Spiracles.*—Spiracularіae moderately stout; mesothoracic pair in a distinct but shallow depression and slightly larger than metathoracic pair.

*Body setae.*—In distribution essentially as in *Thysanococcus chinensis*, with the following variations: 3 dorsomarginal pairs on posterior abdominal segments and 1 mesal pair each on second, third, and fourth abdominal segments more frequently absent in this species; typically 2 ventromesal pairs instead of 1 on posterior section of mesothorax, and 1 ventromesal pair on corresponding section of metathorax instead of none; 4 instead of 6 pairs on anal segment; in all, 23 or 24 pairs present.

*Antenna.*—With 1 single long fleshy seta, 1 partially invaginated pair, and 1 minute slender surface seta.

*Rostralis.*—With one elongate loop and the small cephalic loop, when uncoiled within body. In one specimen, 1.3 mm long.

*Anal segment.*—Caudal margin slightly indented at external openings of about 6 pairs of minute pores; typically 4 pairs of short, delicate forked setae along caudal margin, 1 pair slightly more pronounced in size and sclerotization than the others.

### SECOND-STAGE MALE

(Figs. 53, *H*, and 55)

*Body.*—Anterior and posterior ends about equally rounded; margin firm. Suture between seventh abdominal and anal segments obscure. A typical specimen 0.44 mm long and 0.25 mm wide.

*Pores.*—Both 8-shaped and asymmetrical pores present, intermingling and occurring more or less singly in a pronounced row entirely around the body, except possibly in mesocephalic region of head. On one side of one typical specimen with two 8-shaped pores cephalad of antenna and mesothoracic spiracle, and 1 each on posterior section of mesothorax, each section of metathorax, and second and third abdominal segments; on same side with 4 asymmetrical pores cephalad of antenna, 15 between antenna and mesothoracic spiracle, 14 between spiracles, 7 between metathoracic spiracle and second abdominal segment, 2 each on second and sixth, 1 each on third, fourth, and fifth, and 5 on the 2 posterior abdominal segments; in all, seven 8-shaped and 52 asymmetrical pores present on one side.

*Spiracles.*—Each mesothoracic spiracularia in a distinct but shallow depression.

*Body setae.*—All subequal except a marginal pair on anal segment, which are noticeably larger than the others. Typically 5 pairs on head; 1 ventromarginal pair each on prothorax, posterior section of mesothorax, and each section of metathorax; 1 ventromarginal pair each near margin of second to seventh abdominal segments, inclusive; 1 ventromesal pair each on fifth, sixth, and seventh abdominal segments; 1 dorsomarginal pair each on mesothorax, metathorax, and first, sixth, and seventh abdominal segments; 1 dorsomesal pair each on metathorax and first to sixth abdominal segments, inclusive; 5 pairs on anal segment; in all, 38 pairs present.

*Antenna.*—Typically with 1 large fleshy seta, 3 minute spinelike setae, and 1 pair of apparently partially invaginated setae.

*Rostralis.*—In one specimen, 0.58 mm long.

*Legs.*—Distinguishable but vestigial.

*Exuviation.*—Derm pushed back toward posterior end.

FIGURE 55.—*Thysanococcus pandani*, second-stage male: *A*, Body, dorsal and ventral, × 350; *B*, large submarginal pore (asymmetrical), × 3,000; *C*, small submarginal pore (presumably 8-shaped), × 3,000; *D*, large ventrocaudal seta, × 2,000; *E*, dorsocaudal seta, × 2,000; *F*, antenna, × 2,000.

THIRD-STAGE MALE

(Fig. 56, *H*)

Available material not in condition to distinguish many of the parts adequately, except on posterior end. Body moderately elliptical. One dorsosubmarginal pair of setae on metathorax and each abdominal segment; 1 ventrosubmarginal pair each on fifth, sixth, and seventh abdominal segments; 1 marginal pair on sixth and 2 marginal pairs on seventh abdominal segment; 5 pairs, 1 of which is fleshy and unusually prominent, on anal segment. One specimen 0.45 mm long and 0.26 mm wide.

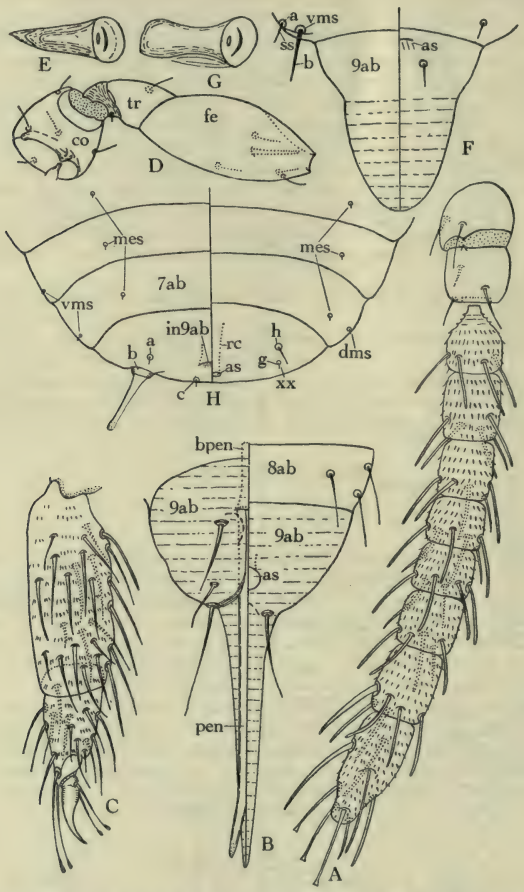


FIGURE 56.—*Thysanococcus pandani: A*, Adult male, antenna, × 400; *B*, same, posterior end, dorsal and ventral, × 400; *C*, same, metathoracic tibiotarsus, × 400; *D*, same, mesothoracic coxa-trochanter-femur, × 400; *E*, same, mesothoracic spiracle, × 1,000; *F*, fourth-stage male, posterior end, dorsal and ventral, × 400; *G*, same, mesothoracic spiracle, × 1,000; H, third-stage male, posterior end, dorsal and ventral, × 400.

FOURTH-STAGE MALE

(Fig. 56, *F* and *G*)

Available material not in condition to distinguish many of the parts clearly. Suboval, with posterior projection mildly rounded and moderately sclerotic for about two thirds of its distal surface. Spiraculariae rather elongate, moderately sclerotic, subequal. With 3 pairs of marginal or submarginal setae, 1 of which is large, spinelike, on eighth abdominal segment, and 1 dorsomesal pair on anal segment. Legs sharply elbowed. One specimen 0.44 mm long and 0.21 mm wide.

ADULT MALE

(Fig. 56, *A–E*)

*Body setae.*—Eighth abdominal segment with 2 marginal pairs and 1 dorsosubmarginal pair; anal segment with 2 comparatively prominent marginal pairs, 1 comparatively prominent ventromesal pair, and 1 smaller ventrosubmarginal pair.

*Antenna.*—Segments of club compactly joined, with all setae on each, except apical one, in a whorl near distal border; scattered on apical segment; on each segment of club from basal to distal one, in order, they number 4, 5, 5, 6, 6, 5, 6, and 8.

*Legs.*—Each mesothoracic leg with 5 and 1 slender setae on coxa and trochanter, respectively, and 4 slender setae and 1 fleshy seta on femur; each metathoracic tibia and tarsus with 25 and 16 scattered setae, respectively; mesothoracic and prothoracic tibiae and tarsi with setae of same character as occur on these segments of metathoracic legs, but less numerous.

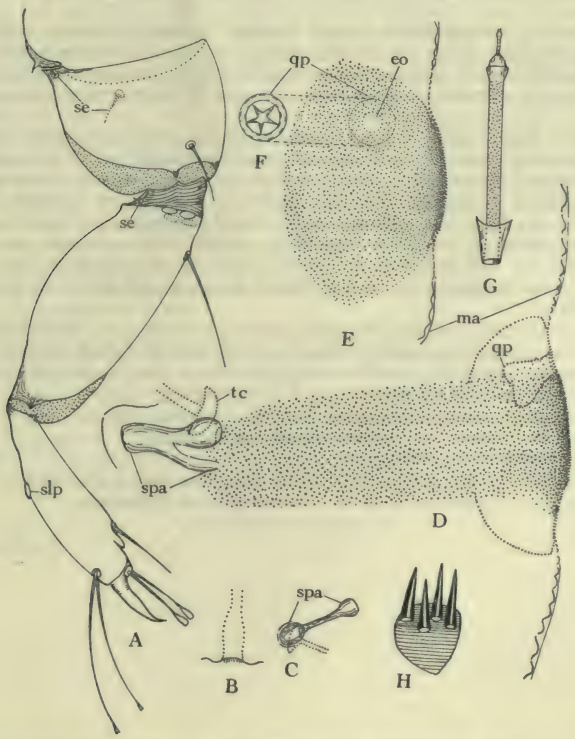


FIGURE 57.—*Thysanococcus squamulatus: A*, First-stage nymph, metathoracic leg, × 1,000; *B*, same, anus, × 1,500; *C*, same, metathoracic spiracle, × 2,000; *D*, *E*, same, mesothoracic spiracular region, ventral and dorsal, respectively, × 2,000; *F*, same, mesothoracic spiracular pore, × 2,000; *G*, same, 8-shaped pore, × 3,000; *H*, egg, spine group, × 1,500.

THYSANOCOCCUS SQUAMULATUS, new species

Two lots, United States Bureau of Entomology; one on *Calamus tetradactylus*, Canton Christian College, Kwantung, China; the other, "on palm tree", Hong Kong, China, collected by George Compere. All specimens exposed on leaves.

EGG

(Fig. 57, *H*)

Oviparous. A single group of 4 or 5 spines moderately spaced and varying but slightly in size; sclerotic body derm extending appreciably around spines.

FIRST STAGE

(Fig. 57, *A–G*)

*Body.*—Marginal serrations faint or obscure; segmentation about as well defined as in *Thysanococcus chinensis.* Clear area laterad of each metathoracic coxa obscure. A typical newly hatched specimen 0.46 mm long and 0.22 mm wide; a fully developed female 0.56 mm long and 0.27 mm wide.

*Pores.*—All 8-shaped pores approximately the same size, small, elongate; partitions extend hardly into distal bars; bars can be distinguished apart without much difficulty; bullae delicate. 8-shaped pores essentially as in *Thysanococcus chinensis,* with the following typical variations: 1 pair on head cephalad of eyes; 1 dorsomesal pair on mesothorax and on each of second, third, and sixth abdominal segments; 1 marginal pair on prothorax and first abdominal segment; in all, 19 pairs present. The quinquelocular pore associated with each mesothoracic spiracle slightly invaginated; opening on dorsum near margin immediately cephalad of external opening of invaginated tube leading to mesothoracic spiracle.

*Spiracles.*—The invaginated tubes leading to mesothoracic spiracles nearly straight and broader than in *Thysanococcus chinensis;* their external openings obscure. Mesothoracic spiracularіae moderately elongate, distinctly sclerotic; metathoracic pair distinctly more slender and less sclerotic than mesothoracic pair.

*Body setae.*—Essentially as in *Thysanococcus chinensis,* with the following typical variations: Second ventromesal pair on head not comparatively long, and 1 of marginal pairs on head cephalad of eyes absent; dorsomesal pair on prothorax absent; a single marginal pair on dorsum of metathorax, and no marginal pairs on first and second abdominal segments; 1 minute ventrosubmarginal pair each on at least the fifth, sixth, and seventh, and apparently sometimes also on the third and fourth, abdominal segments; in all, 50 pairs present. In one specimen, outer and inner long caudal setae 25 and 80 microns long, respectively.

*Antenna.*—Essentially as in *Thysanococcus chinensis,* with the following typical variations: Third seta apparently absent; fifth seta vestigial; sixth, seventh, and eighth setae more apical in position than in above-mentioned species.

*Rostralis.*—In one typical specimen, 0.71 mm long.

*Legs.*—Trochanter and femur, and tibia and tarsus, fused. No setae on femur or tibia; spinelike process of tarsus slightly projecting.

*Anal ring.*—Apparently absent.

*Exuviation.*—In female essentially as in *Thysanococcus pandani.*

*Dried material.*—Essentially as in *Thysanococcus chinensis.*

### SECOND-STAGE FEMALE

(Fig. 58, *A–D*)

*Body.*—Moderately elliptical, with cephalic and caudal margins rounded similarly in both young and old specimens. Marginal fringe distinct; not so pronounced but of the same character as in *Thysanococcus chinensis;* extending all around cephalic margin and caudad to about fourth abdominal segment, where it terminates rather abruptly. Ventromarginal surface covered with faint papillae, of same character as in *Thysanococcus chinensis*, but considerably less pronounced; dorsal surface entirely reticulated except for a more or less bare area immediately over head skeleton. A typical young specimen 0.52 mm long and 0.22 mm wide; a puparium typically 0.63 mm long and 0.33 mm wide.

*Pores.*—Both ordinary and variating kinds of 8-shaped pores present. Ordinary kind of 8-shaped pore small, elongate, and delicate; external openings flush with surface; restricted to a row along ventrosubmarginal surface; typically 5 to 7 pairs on head and thorax together, and 1 pair on each abdominal segment to and including the seventh. Variating kind of 8-shaped pore moderate in size and relatively prominent, owing largely to its sclerotization; occurring along dorsomarginal surface, from and including the head to and including the fifth or sixth abdominal segment; in about 10 groups of usually 1, less frequently 2, and sometimes 3 or 4 pores in each group; also 2 to 7 pairs occurring dorsomesally on thorax or abdomen, or both; on one side of one typical specimen 16 dorsomarginal and 4 dorsomesal pores of this variating kind counted. Typically 1 quinquelocular pore associated with each mesothoracic spiracle; no others present.

*Spiracles.*—In structure and form mesothoracic invaginated tubes and spiraculariae of both pairs of spiracles approximately as in *Thysanococcus pandani.*

*Body setae.*—In occurrence and position essentially as in *Thysanococcus chinensis*, except ventromesal pair on thorax apparently absent, and apparently 2 or 3 less pairs present on anal valve.

*Antenna.*—With a single prominent fleshy seta and a pair of comparatively large partially invaginated setae.

*Rostralis.*—With 1 elongate loop, 2 large roundish loops, and the small cephalic loop, when uncoiled within body; in one typical specimen, 2.0 mm long.

*Anal valve.*—Posterior half of covering tissue with faint markings resembling spiny reticulations, or markings may be obscure; apparently without pores; with about 4 pairs of minute setae on or near caudal margin; anus near caudal margin; anal ring apparently absent.

*Dried material.*—Approximately as in *Thysanococcus chinensis*, but dorsum tapering a little more gently posteriorward.

### THIRD-STAGE FEMALE

Not identified.

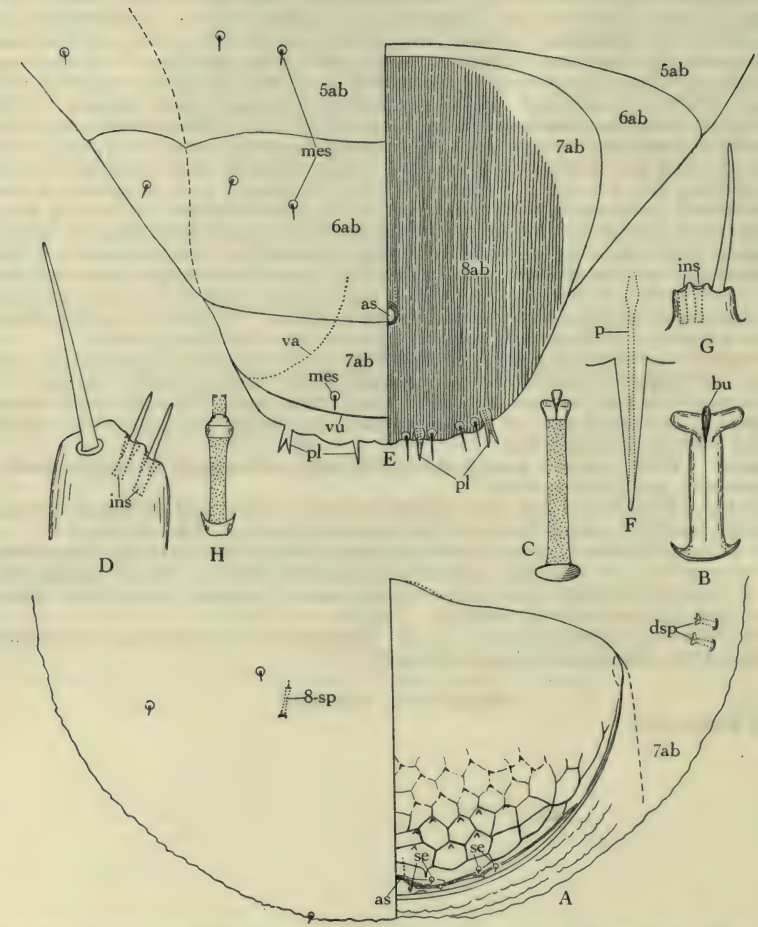


FIGURE 58.—*Thysanococcus squamulatus: A*, Second-stage female, posterior end, dorsal and ventral, × 500; *B*, same, dorsosubmarginal 8-shaped pore (variating kind), × 3,000; *C*, same, ventrosubmarginal 8-shaped pore (ordinary kind), × 3,000; *D*, same, antenna, × 2,000; *E*, adult female, posterior end, dorsal and ventral, × 500; *F*, same, caudal plate or squamula (apparently containing delicate pore), × 3,000; *G*, same, antenna, × 2,000; *H*, same, midventral 8-shaped pore, × 3,000.

ADULT FEMALE

(Fig. 58, *E–H*)

*Body.*—Moderately elliptical, with posterior end curving slightly mesad along its lateral margin and projecting somewhat less broadly than in *Thysanococcus chinensis;* seventh abdominal and anal segments apparently fused on dorsum; dorsal surface of sixth abdominal segment defined, that of other segments obscure; dorsal sclerotization of posterior end covering apparently all of anal segment and much of mesal region of seventh abdominal segment. A typical specimen 0.52 mm long and 0.28 mm wide.

*Pores.*—From 4 to 12 8-shaped pores scattered on each side of body, apparently limited to posterior section of metathorax; partitions, even into bars, apparently absent; bars can be distinguished from each other; bullae relatively broad; external openings at apices of sclerotic projections.

*Spiracles.*—Spiracullariae moderately elongate, subequal.

*Body setae.*—Essentially as in *Thysanococcus chinensis*, with the following typical variations: Apparently no dorsomarginal setae on posterior segments; no ventromesal setae on thorax, and a single pair each on second and third abdominal segments; 4 pairs, instead of 6, on anal segment; in all, 23 pairs present.

*Antenna.*—With one large fleshy seta and a pair of rather stout setae, moderate in size and partially invaginated.

*Rostralis.*—With 1 elongate loop, 2 large roundish loops, and the small cephalic loop, when uncoiled within body; in one typical specimen, 2.7 mm long.

*Anal segment.*—Caudal margin slightly wavy; typically with 2 or 3 pairs of small delicate plates or squamulae, which may or may not be forked, projecting from laterocaudal margin; these plates frequently appearing to possess delicate elongate pores which open externally on or near apices of plates; with 4 pairs of subequal setae along caudal margin. Anus apparently centrally located; pronounced in appearance; apparently with anal ring, but no anal-ring setae in evidence.

MALE STAGES

Not available.

THYSANOCOCCUS CALAMI, new species [13]

Material from E. E. Green; on *Calamus* sp., Buitenzorg, Java, collected by A. Zimmermann; United States Bureau of Entomology, on "rottang" ("creeper palm of the tropical forests"), Buitenzorg, Java, received through T. D. A. Cockerell, May 31, 1911. All specimens exposed on leaves.

EGG

(Fig. 59, *E*)

Apparently oviparous. With a group of 8 or 9 spines, distinctly crowded and varying in size; sclerotic body derm practically not extending beyond bases of spines.

[13] See footnote 12, p. 127.

FIRST STAGE

(Fig. 59, *A–D*)

*Body.*—Marginal serrations obscure; segmentation of head, prothorax, and mesothorax ill defined. Clear area laterad of each metathoracic coxa distinct. A newly hatched specimen 0.23 mm long and 0.11 mm wide; a fully developed female 0.44 mm long and 0.19 mm wide.

*Pores.*—All 8-shaped pores approximately uniform in size; small, with possible exception of 1 ventromarginal pair on seventh abdominal segment; confined to

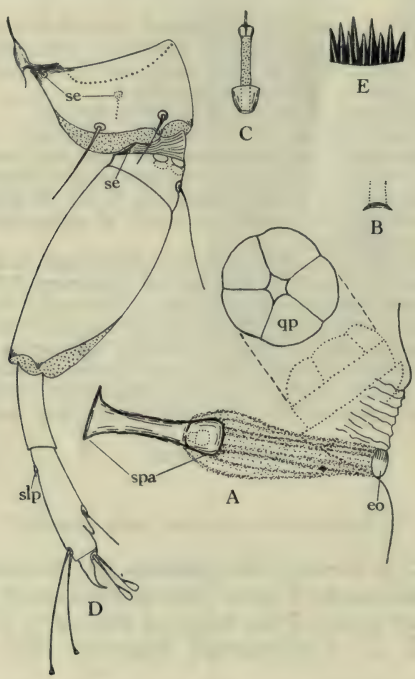


FIGURE 59.—*Thysanococcus calami: A,* First-stage nymph, mesothoracic spiracle, ventral, × 2,000; *B,* same, anus, × 1,500; *C,* same, 8-shaped pore, × 3,000; *D,* same, metathoracic leg, × 1,000; *E,* egg, spine group, × 1,500.

dorsum typically as follows: 1 pair on head, cephalad of eyes; 1 pair each near margin of prothorax, metathorax, and all abdominal segments, except possibly the third; 1 mesal pair on all thoracic segments and the second abdominal segment; in all, 15 pairs of 8-shaped pores present. The quinquelocular pore associated with each mesothoracic spiracle relatively large, emarginated, slightly invaginated, and situated cephalad of invaginated tube leading to spiracle.

*Spiracles.*—Invaginated tubes leading to mesothoracic spiracles straight, somewhat shorter than in *Thysanococcus chinensis.* Spiracullariae elongate, distinctly sclerotic, subequal. No differentiated area on margin near invaginated tubes leading to mesothoracic spiracles.

*Body setae.*—Essentially as in *Thysanococcus chinensis,* with the following additional setae: 1 minute pair on dorsal margin of apparently the anterior section of mesothorax; 1 lateromesal pair of dorsum each on mesothorax and metathorax; 1 minute ventrosubmarginal pair each on second to seventh abdominal segments, inclusive; 1 minute ventromesal pair on sixth abdominal segments; in all, 62 pairs present. In one specimen, outer and inner long caudal setae 31 and 156 microns long, respectively.

*Antenna.*—Approximately as in *Thysanococcus chinensis,* except for possible absence of the minute seta on third segment.

*Rostralis.*—In one typical specimen, 0.60 mm long.

*Legs.*—In essentials as in *Thysanococcus chinensis,* except femur more slender, tibia slightly longer, and spinelike process of tarsus more pronounced.

*Anal ring.*—Essentially as in *Thysanococcus chinensis.*
*Exuviation.*—Essentially as in *Thysanococcus chinensis.*
*Dried material.*—Light to rich brown; less flat than in *Thysanococcus chinensis;* a marginal fringe of discolored wax observed in some specimens.

SECOND-STAGE FEMALE

(Fig. 60, *C–F*)

*Body.*—Elongate elliptical, with cephalic margin slightly more broadly rounded than caudal margin. In structure and extent marginal fringe approximately as in *Thysanococcus chinensis;* with pronounced characteristic irregular marginal indentations, fully lined with the marginal fringe; no other noticeable dermal configuration. Puparium heavily sclerotic on dorsum; derm distinctly brittle in all prepared specimens. A typical newly molted specimen 0.35 mm long and 0.14 mm wide; a puparium 0.54 mm long and 0.23 mm wide.
*Pores.*—8-shaped pores rather small; of the ordinary kind only; typically 3 to 5 pairs scattered immediately caudad of metathoracic spiracles, a like number scattered dorsomesally on fifth or sixth abdominal segment, and an occasional pore elsewhere; bullae delicate, relatively broad; external openings on sclerotic conical projections. Typically 2 subequal quinquelocular pores associated with each mesothoracic spiracle. Typically about 17 groups of quinquelocular pores, each possessing from 1 to 3 pores, in a row extending entirely around body margin; 29 and 31 pores counted on single sides of two specimens.
*Spiracles.*—Invaginated tubes of mesothoracic spiracles extending from latter toward margin in a fairly straight line; these tubes comparatively broad and faintly granulate. A broad granulate band present along margin in immediate vicinity of external openings of mesothoracic invaginated tubes. Mesothoracic spiraculariae larger than metathoracic ones.
*Body setae.*—Essentially as in *Thysanococcus chinensis,* with the addition of 1 pair on cephalic margin of head, the distinct enlargement of the pair on or near caudal margin of seventh abdominal segment, and the apparent absence of 1 pair on edge of anus, but with 7 pairs on anal valve; in all, 25 pairs present.
*Antenna.*—With a single fleshy seta more or less apically situated, 1 minute slender surface seta, and a minute pair of wholly invaginated setae.
*Rostralis.*—With 1 elongate loop, 2 large roundish loops, and the small cephalic loop, when uncoiled within body; in one specimen, 1.8 mm long.
*Anal valve.*—Covering tissue faintly reticulated; pores apparently absent; with 7 pairs of small setae near lateral and caudal margins. Anus small, distinctly caudad in position, but not on margin; anal ring may be present; if so, narrow; anal-ring setae apparently absent.
*Dried material.*—Puparium dark brown to almost black; a fringe of discolored matted wax usally present around margins; body distinctly depressed but not flat; posterior end pointed nearly straight dorsad; body covered with first-stage exuvia.

THIRD-STAGE FEMALE

Present but too delicate to distinguish any parts.

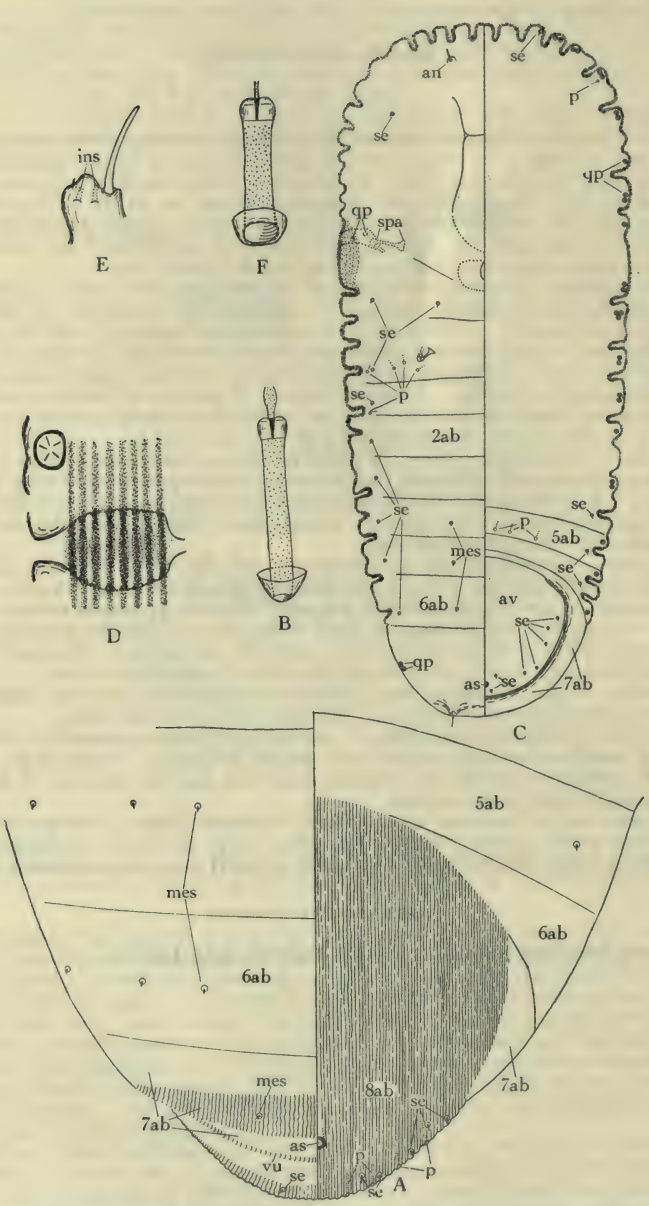


FIGURE 60.—*Thysanococcus calami: A*, Adult female, posterior end, dorsal and ventral, × 500; *B*, same, mid-ventral 8-shaped pore, × 3,000; *C*, second-stage female, body, dorsal and ventral, × 265; *D*, same, looking down on fringe, × 2,000; *E*, same, antenna, × 2,000; *F*, same, 8-shaped pore, × 3,000.

ADULT FEMALE

(Fig. 60, *A* and *B*)

*Body.*—Elongate elliptical, with posterior end projecting only slightly and less roundly than in *Thysanococcus chinensis;* seventh abdominal and anal segments fused, and mesal region of sixth apparently fused with that of seventh abdominal segment; dorsal surface of fifth abdominal segment defined; dorsal sclerotization covering all of anal segment and almost all of seventh, and possibly mesal region of sixth abdominal segment; a distinct ridged effect across ventral surface of seventh abdominal segment. A typical specimen 0.53 mm long and 0.17 mm wide.

*Pores.*—In structure and position 8-shaped pores essentially as in *Thysanococcus chinensis,* but clusters confined almost to posterior section of metathorax and the following (second abdominal) segment; on these 2 segments, 24 counted on one side of one specimen.

*Spiracles.*—Mesothoracic spiracularіae somewhat enlarged at their mesal ends, and slightly larger than metathoracic pair, which are rather elongate.

*Body setae.*—Essentially as in *Thysanococcus chinensis,* with the following typical variations: 2 pairs usually observed on dorsal surface of head; apparently none on prothorax; 1 pair sometimes observed on or near margin laterad of mesothoracic spiracles; 1 mesal pair on anterior section of metathorax; 3 pairs on dorsal margin near posterior end, apparently on third, fourth, and fifth abdominal segments; only 1 ventromesal pair each on second and third abdominal segments; in all, 30 pairs present.

*Antenna.*—With 1 large fleshy seta, 1 pair of small wholly invaginated setae, and apparently 1 minute surface seta.

*Rostralis.*—Not available.

*Anal segment.*—Caudal margin faintly crenulate; typically with 4 pairs of 8-shaped pores and 6 pairs of subequal setae along laterocaudal margin; anus apparently situated caudad of center; anal ring apparently present, but anal-ring setae absent.

MALE STAGES

None at hand, except one adult in poor condition, with no vestige of thoracic wing framework or of wings, with two pairs of eyes.

## RELATION TO OTHER COCCIDS

After reading the manuscript of this bulletin, G. F. Ferris made the following statement concerning the species here included in the Phoenicococcini and their relation to other coccids:

The problem of the relationships of the group of palm-infesting species here dealt with to other members of the Coccoidea (Coccidae) is a difficult one. In the first place, the general classification of the superfamily (or family) is at present only partially satisfactory, there being disagreement among authorities as to the relationship and rank of even the more clearly defined groups. And aside from such groups there exist many forms that do not fit with any of the more distinct groups and the disposal of which is a problem that has yet been but little elucidated.

The palm-infesting species here considered constitute such a problem. That they are actually related to each other seems obvious and their inclusion in some common category—whether it be called a subfamily or a family—appears adequately justified on the basis of present knowledge. But their possible connections with other groups are extremely obscure. They are most certainly not immediately connected with any of the typical and well-known groups. If their connections are to be traced at all, it must be through a study of some lesser known species in the hope that somewhere there will be found forms that may possibly serve as links with the more familiar types. The presence of the 8-shaped pores leads one naturally to a consideration of the Asterolecaniidae, and certain other features compel a consideration of some strange forms which have in the past been referred to the Diaspidae. Out of all the immense assemblage of forms in the Coccoidea these seem to offer the most promising leads for investigation.

In the search for near relatives of the Phoenicococcini, the margarodine, ortheziine, eriococcine, pseudococcine, coccine, and tarchardiine assemblages may be eliminated, since in each of these occur three or more of such characteristic features as the following, none of which are present in the Phoenicococcini: Abdominal spiracles, compound eyes or ocelli, distinctly developed antennae or legs in other than the first and three later male stages, monolocular or multilocular [14] disk pores, anal-ring pores, pronounced and well-distributed setigerous areas, dorsal ostioles, cerarii, anal clefts, anal plates, brachial plates, dorsal spines, gall formations, or resinous secretions. Of the well-known groups there remain the asterolecaniine and diaspine ones. The occurrence among most of the former of such characteristics as monolocular or multilocular [14] disk pores, more or less sessile 8-shaped pores, cribiform plates, and, in the first stage, of a markedly indented caudal margin, more or less clearly defined sclerotic anal areas, and a setigerous development in the anal region distinctly unlike that in the Phoenicococcini eliminates them from consideration. Yet two species examined, which have been assigned, apparently justly, to the asterolecaniine group, possess none of the above-mentioned characteristics, having, in fact, no structural features that seem to be widely at variance with those in the Phoenicococcini; and when it is noted that the same two general types of tubular pores occur in these two species and the latter, a relationship in one direction is indicated.

To the diaspine assemblage have been assigned a number of rather obscure forms showing varying degrees of similarity to the Phoenicococcini. One genus has at least one species remarkably like the Phoenicococcini, possessing no structural features, with the possible exception of the character of the anal valve in the second-stage female, apparently at serious variance with those in the Phoenicococcini; and since this species and at least one more in this genus clearly quite close to it show definite characteristics of being generalized diaspids, a relationship in another direction is indicated. If these relationships are valid and the species concerned belong in the groups in which they have been placed, then the asterolecaniine and diaspine groups are at least remotely connected.

The following discussion will deal first with a few asterolecaniine species and some other forms that are more or less generalized, and secondly, with a number of diaspine species, which because of certain points of similarity to the Phoenicococcini may help to throw light on the relationships of the latter. Particular attention is given to the character of the pores occurring among the various species studied, as this feature seems to be of most significance from the standpoint of relationships.

## SOME ASTEROLECANIINE AND OTHER FORMS

The pores of the first stage of the asterolecaniine form *Mycetococcus ehrhorni* Cockerell (fig. 61) are limited to a normally trilocular disk and a tubular 8-shaped type. The trilocular pores are associated with each spiracle only, and the 8-shaped pores are comparable in extent of invagination, size, number, and distribution with those in this stage, for example, in *Phoenicococcus marlatti*. This tubular type of pore does not differ essentially from that occurring in the Phoeni-

[14] Used here in the sense of having more than five loculi.

cococcini, except that it seems to possess a single, only moderately sclerotic bar, a moderately sclerotic tube connecting the bar with the exterior, a partition extending completely through the bar and tube, producing a double or 8-shaped external opening, and possibly a bulla issuing from the center of the inner surface of the bar but

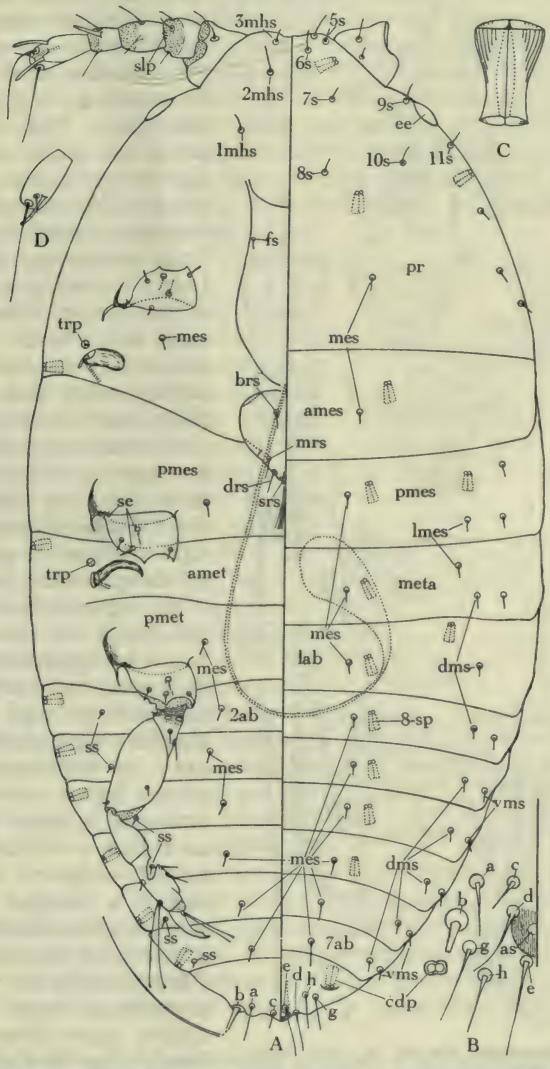


FIGURE 61.—*Mycetococcus ehrhorni*, first-stage nymph: *A*, Body, dorsal and ventral, × 500; *B*, anal region, × 1,200; *C*, tubular 8-shaped pore, × 3,000; *D*, antenna, apical segment, dorsal, × 500.

too delicate to be clearly discerned. In the possession of a single moderately sclerotic bar and a tube approximately equally sclerotic this pore of *M. ehrhorni* resembles most nearly the variating kind of 8-shaped pore occurring in the second-stage female of *Thysanococcus squamulatus* (fig. 58), the only significant difference between the two

being that in the latter species the partition is more delicate and disappears just before the external opening.

The body setae of the first stage of *Mycetococcus ehrhorni* are not essentially different from those of the Phoenicococcini except in the following respects: Only one long caudal pair is present, and the anal-ring or homologous setae are of the same general size as other setae of this region, and stable in occurrence. But these latter setae are of the same number and in the same general positions as, for example, in *Phoenicococcus marlatti* (fig. 2), and thus give every indication of being homologous with those of the latter. Since the anal-ring setae in *P. marlatti* are somewhat smaller than neighboring setae and two pairs of them are distinctly unstable in occurrence, and these are in varying degrees even less in evidence in other species of the Phoenicococcini, it appears that such setae are in process of disappearing in this tribe.

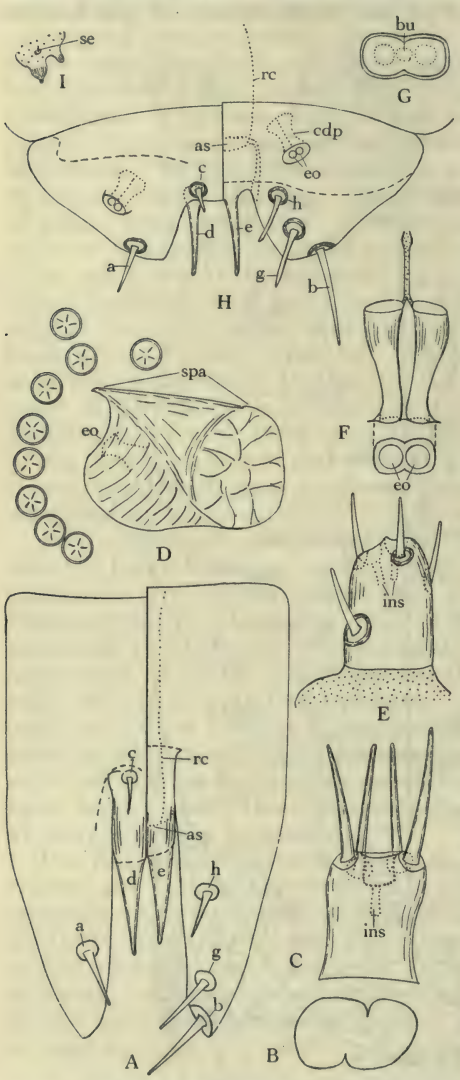


FIGURE 62.—*Mycetococcus ehrhorni:* *A*, Adult female, posterior end, dorsal and ventral, × 400; *B*, same looking down on inner end of 8-shaped pore, × 3,000; *C*, same, antenna, × 1,000; *D*, same, mesothoracic spiracle, × 1,000; *E*, second-stage female, antenna, × 1,000; *F*, same, tubular 8-shaped pore, × 3,000; *G*, same, looking down on inner end of tubular pore, × 3,000; *H*, same, posterior end, dorsal and ventral, × 400; *I*, same, metathoracic leg, × 1,500.

As regards the remainder of the body in the first stage, there is apparently no more difference between *Mycetococcus ehrhorni* and a species in the Phoenicococcini than there may be between two species of the latter, except that the antenna is only 5-segmented and has a slightly enlarged apical segment, which possesses a larger number of slender setae than are present in the 6-segmented type of the Phoenicococcini; yet the 6-segmented type of antenna differs more from the annulated type in this tribe than from the antenna in *M. ehrhorni*.

In the second and adult female stages of *Mycetococcus ehrhorni* (fig. 62) the pores are limited to quinquelocular and trilocular disk types and a tubular 8-shaped type. The quinquelocular pores are associated with the spiracles and the trilocular pores are situated laterad of the head skeleton. The 8-shaped pores are distributed generally

over the body in both these stages and are plainly double throughout except for a single centrally located distinct bulla to each pore. They are in no essentials different from the first-stage tubular pores, except that the bullae are not distinct in the latter. A twisted 8-shaped effect was frequently observable across the inner surface of the bar of a tubular pore, especially in the adult stage. This effect is probably due to distortion from the flattening out of the rotund bodies on slides, for the normal 8-shaped effect was also noted.

The anus is noticeably invaginated in the second-stage female of *Mycetococcus ehrhorni* and more so in the adult stage, with stouter setae around it in both stages than are present in the first stage of this species, or in the Phoenicococcini; but these anal setae are apparently homologous with those in the first stage of this species and of the latter. All other parts of the body in these two female stages are not greatly dissimilar to the corresponding parts in the Phoenicococcini.

The second-stage male of *Mycetococcus ehrhorni* (fig. 63) has the same disk types of pores, and these are situated as in the female stages. The tubular pores appear significant. The typical ones have delicate tubes, also distinctly sclerotic, seemingly single bars, and bullae arising from the sides of the bars; thus, as far as can be judged, these pores are essentially like the asymmetrical ones occurring in this stage of *Halimococcus thebaicae* (fig. 35) and *Thysanococcus pandani* (fig. 55). They are distributed generally over the body. In some specimens apparently the identical kind of 8-shaped pore occurring in the female stages is sparsely scattered over the body. It resembles a union of two of the usual type, the bars and tubes simply coming into juxtaposition but the bullae completely fusing. The two posterior segments are like those of the second-stage female except for the above-mentioned difference in pore structure and in the possession of one mesal pore on each surface of each segment. Legs are present and distinct though vestigial, and the antenna is tuberculate but plainly segmented; thus in these particulars, as well as in all others, this stage is apparently essentially like that in the Phoenicococcini.

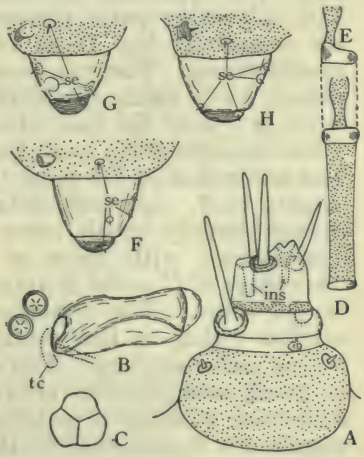


FIGURE 63.—*Mycetococcus ehrhorni*, second-stage male: *A*, Antenna, × 1,000; *B*, mesothoracic spiracle, × 1,000; *C*, trilocular pore laterad of head skeleton, × 2,000; *D*, tubular pore, × 3,000; *E*, same pore, turned partly around, × 3,000; *F*, metathoracic leg, × 1,500; *G*, mesothoracic leg, × 1,500; *H*, prothoracic leg, ×1,500.

The adult male of *Mycetococcus ehrhorni* is strikingly similar to males of the Phoenicococcini in that it has a closely joined head and thorax, no vestige of wings or of thoracic wing framework, a pair of simple eyes, setae of the same general character, and a single rapierlike posterior projection which is slightly stout, being much like that in *Phoenicococcus marlatti* (fig. 9). Unfortunately, the apical part of each antenna was lost in the specimens at hand; so no observations on this structure were possible.

The 8-shaped pores of the Phoenicococcini might be considered as having been derived from such a type as those of *Mycetococcus ehrhorni*, since in the former the partition is apparently present in all degrees, from being complete nearly to the external opening to entirely disappearing in the tubes. Furthermore, since the Phoenicococcini possess a variating kind noticeably like the typical 8-shaped type in *M. ehrhorni*, apparently the same kind of asymmetrical tubular pores and only the same other pore types as this species, and since no serious structural differences seem to exist in the corresponding stages, and there is no apparent difference in the character of the waxy secretions of each, it seems reasonable to believe that *Mycetococcus ehrhorni* and the Phoenicococcini are related.

The first stage of the asterolecaniine form *Capulinia sallei* Sign. (fig. 64) has quinquelocular-disk pores associated with the spiracles instead of trilocular ones as in this stage of *Mycetococcus ehrhorni*. The only other pores present are of the double tubular type, which are essentially like those of *M. ehrhorni* except for the following modifications: The two component parts of a pore are less closely joined, there being a distinct separation of parts of the tubes and more or less of the bar, which is perhaps more sharply sclerotic, the tubes membranous, and the single bulla distinct though delicate. The antenna is of the same type as in *M. ehrhorni* but has 6 segments instead of 5. All body setae, including those of the posterior end, though largely much more developed, can apparently be readily homologized with those of *M. ehrhorni* and the Phoenicococcini. This stage of *C. sallei* is unusual in the possession of two pairs of long caudal setae. The importance of this fact should be judged with caution owing to the modified development of other setae in this region and elsewhere. The extent of the anal ring is obscure owing to much sclerotization around the anus. This makes it difficult to determine whether or not the anal ring is present at all, for unless it stands out rather sharply its use as a systematic factor may prove misleading. The anus is somewhat evaginated, instead of invaginated as in *M. ehrhorni*, and more or less flush with the surface as in the Phoenicococcini. No parts of the body, however, are considered to be at great variance with those in *M. ehrhorni* and the Phoenicococcini.

In the second and adult female stages of *Capulinia sallei* (fig. 64) the double and single types of tubular pores, essentially of the same character as are found in the female and second male stages, respectively, in *Mycetococcus ehrhorni*, occur together, with a preponderance of the single type present, especially in the adult female. The double pores are approximately twice the size of the single ones, are loosely joined as in the first stage of this species, and strongly suggest that each has resulted from a coalescence of two of the single ones.

*Capulinia sallei* possesses no pore types not present in some stage of *Mycetococcus ehrhorni* and, except perhaps for the presence of one or more pairs of vestigial legs, no structures apparently exist in the female stages of this species which differ greatly from those of *M. ehrhorni;* also the waxy secretions of both are essentially of the same character, being cottony in texture as in the Phoenicococcini. But the adult male of *C. sallei* has a well-developed thoracic wing framework (though the wings are apparently rather vestigial or absent), a pronounced constriction between the head and the thorax, setigerous areas, and two pairs of simple eyes.

With so many characteristics in common it seems reasonable to believe that *Mycetococcus ehrhorni* and *Capulinia sallei* are definitely related; and, likewise, that the latter species is related to the Phoenicococcini, but probably less so than is *M. ehrhorni*, chiefly because of the more loosely joined character of the 8-shaped tubular pores, the presence of the asymmetrical type of tubular pore in the female stages, and the more distinguishing differences in the adult male.

The double or 8-shaped type of pore of a more typical asterolecaniine species may be tubular as in *Callococcus pulchellus* Maskell (fig. 65, *F*), virtually sessile as in *Asterolecanium pustalans* Cockerell (fig. 65, *G*), in a slight invagination as in *Lecaniodiaspis tessellata* Cockerell (fig. 65, *C*, *D*), or in a more pronounced invagination as in *Pollinia ovoides* Cockerell (fig. 65, *E*). The type in *C. pulchellus* appears to be essentially like that in *Mycetococcus ehrhorni* and in *Capulinia sallei*, but to be nearer the sessile condition. In *L. tessellata*, from the appearance of the 8-shaped parts, which apparently conform strictly to the condition in the sessile type of pore, the slight invagination present, apparently no more than a mere indentation in the body wall, is considered to be a later development from the sessile type. The situation of the 8-shaped pore in *P. ovoides* would apparently be simply a step further. Incidentally, in later female stages of the latter the 8-shaped pores are almost sessile. Thus the types of 8-shaped pores in all the above-mentioned asterolecaniine forms appear to bear a fundamental relation to one another. If this is so, then on the basis of the discussion already given, the 8-shaped

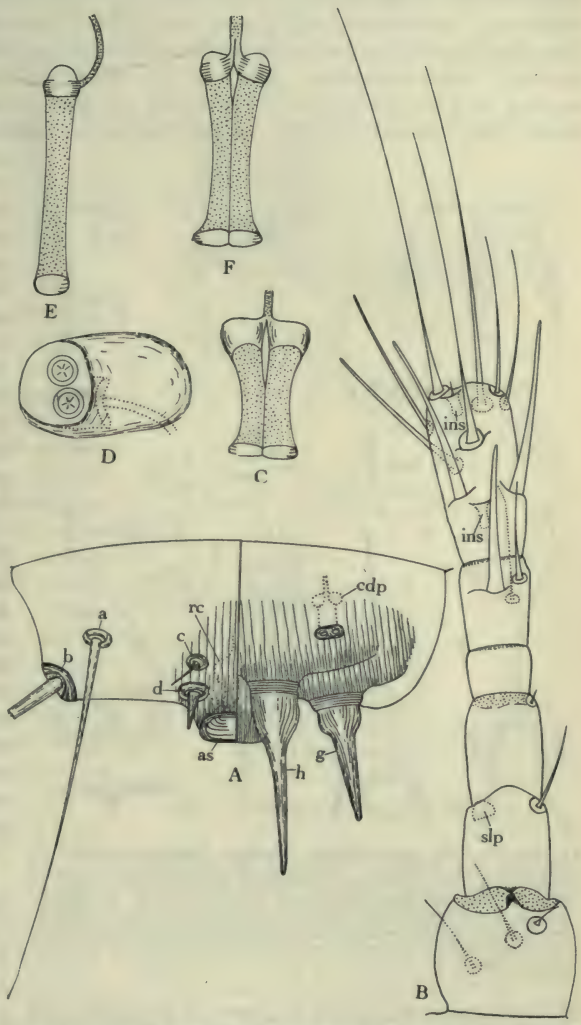


FIGURE 64.—*Capulinia sallei: A*, First-stage nymph, posterior end, dorsal and ventral, × 1,000; *B*, same, antenna, × 1,000; *C*, same, tubular 8-shaped pore, × 3,000; *D*, same, mesothoracic spiracle, × 1,000; *E*, adult female, tubular asymmetrical pore, × 3,000; *F*, same, tubular double pore, × 3,000.

pores of the Phoenicococcini would be connected with those of the typical asterolecaniine forms through the type occurring in such species as *M. ehrhorni* and *C. sallei*. Also, in later stages of all these more typical asterolecaniine species occurs a long membranous tubular type of pore, with the bulla issuing from one side, apparently identical with the asymmetrical tubular type occurring in *Mycetococcus ehrhorni*, *Capulinia sallei*, and the Phoenicococcini. But owing to the absence of the features previously mentioned as occurring among typical asterolecaniine species, *M. ehrhorni* and *Capulinia sallei* appear not to be typical members of the group. However, since these two species have so many points in common with the typical asterolecaniine species, such as apparently related 8-shaped pores and essentially the same type of asymmetrical tubular pores, and possess no structures that seem to justify removing them from the general asterolecaniine group, it is suggested that they be placed in a separate tribe of this group.

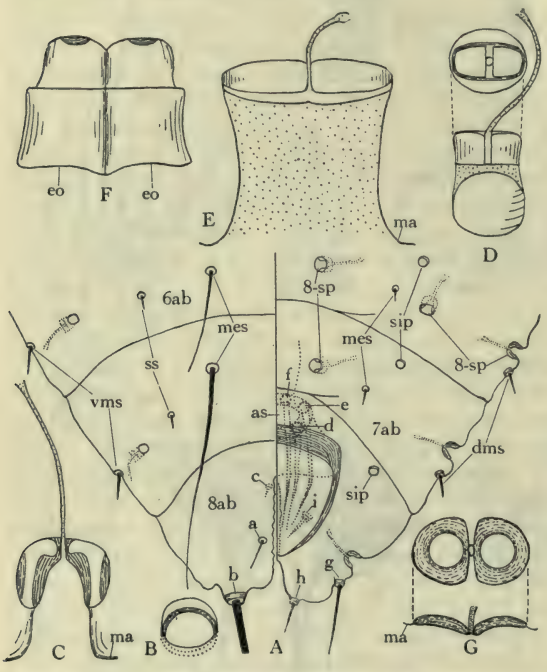


FIGURE 65.—*A–D*, *Lecaniodiaspis tessellata*, first-stage nymph: *A*, Posterior end, dorsal and ventral, × 500; *B*, slightly invaginated simple pore, dorsal, × 3,000; *C*, 8-shaped marginal pore, dorsal, × 3,000; *D*, 8-shaped submarginal pore, ventral, × 3,000. *E*, *Pollinia ovoides*, first-stage nymph, 8-shaped tubular pore, × 3,000. *F*, *Callococcus pulchellus*, first-stage nymph, tubular 8-shaped pore, × 3,000. *G*, *Asterolecanium pustulans*, first-stage nymph, marginal 8-shaped pore, × 3,000.

The posterior end of *Lecaniodiaspis tessellata* (fig. 65, *A*) is figured to show the character of the pores and to indicate the probable homologies of the parts occurring here of a typical asterolecaniine as compared with this region in other coccid species treated in this bulletin.

That the tubular type of 8-shaped pore is not restricted to a narrow range is indicated by the fact that along the ventrosubmarginal surface of the abdomen in the second and adult female stages of the obscure form *Kuwanina parvus* Maskell (fig. 66, *C* and *D*) occur a few small delicate 8-shaped pores, essentially of the type in the Phoenicococcini and resembling especially the 8-shaped pores occurring in the genera *Phoenicococcus* and *Palmaricoccus*. The only other type seen was the quinquelocular-disk one, the pores of which were either rather large and scattered over the body or comparatively small and mostly localized in the midventral region. The two above-mentioned stages possess eyes, segmented but much reduced

antennae, all three pairs of legs, though in vestigial form, a faintly segmented rostrum, but a posterior end not greatly unlike that in the first stage of *Phoenicococcus marlatti*, though with eight pairs of well-developed setae. In the first stage of *K. parvus* (fig. 66, *G–I*) a few rather large quinquelocular pores are scattered over the body, with no other pore type observed except an irregular band of apparently anal-ring pores. Excluding these differences and that of an extra pair of setae and of only one prominent caudal pair, the posterior end in this stage is approximately like that in *P. marlatti*. It appears not unlikely that *K. parvus* may be a distant relative of the Phoenicococcini, but it does not seem to fit in well with any recognized group of coccids.

In another obscure form, *Stictococcus multispinosus* Newstead (fig. 66, *A*), tubular 8-shaped pores occur around the ventral margin and submargin of what is presumably the adult female. The pores are fairly large, have broad bullae, two more or less sclerotic bars, a membranous tube, and a double external opening. Except for the last-mentioned characteristic, they resemble the 8-shaped pores of the Phoenicococcini more than those of other coccids mentioned above. Tubular 8-shaped pores also occur in several margarodine genera.

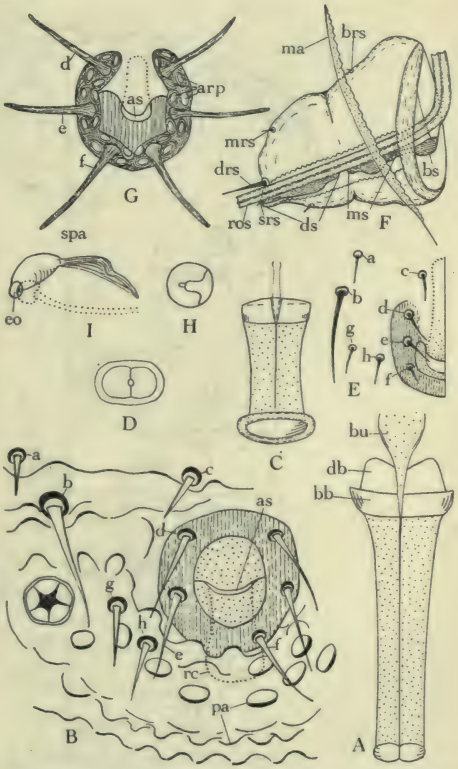


FIGURE 66.—*A*, *Stictococcus multispinosus*, adult female (?): Tubular 8-shaped pore, × 3,000. *Kuwanina parvus*: *B*, Adult female, anal region, × 1,000; *C*, same, tubular 8-shaped pore, × 3,000; *D*, same, looking down on inner end of 8-shaped tubular pore, × 3,000; *E*, second-stage female, anal region, × 1,000; *F*, same, lateral aspect of rostrum, × 1,000; *G*, first-stage nymph, anal ring, × 1,000; *H*, same, clear area laterad of metathoracic coxa, × 3,000; *I*, same, mesothoracic spiracle, × 1,000.

## SOME DIASPINE FORMS

A single type of pore only is observed through the various stages of *Ancepaspis edentata* Ferris, an invaginated 8-shaped one with a centrally located bulla, 2 bars, and a membranous tube. The partition extends through both bars but apparently not into the tube. As far as can be seen, this type of pore is like that in the Phoenicococcini. The only features in the first stage (fig. 67) by which this species can be well separated from the Phoenicococcini are the presence of a pair of rudimentary diaspid lobes and the absence of one pair of long caudal setae. Even the antennae are essentially like those of the Phoenicococcini. The second-stage female of *A. edentata*

is puparial (fig. 68), with an apparently functional anal valve on the dorsal surface. This valve differs from that in the Phoenicococcini in that it apparently embraces, besides the eighth, the dorsal surface of the seventh and sixth abdominal segments, is not depressed below the surrounding region, and has its laterocaudal margins not sharply defined, appearing in fact to be in process of coalescing with the bordering tissue; whereas in the Phoenicococcini the anal valve includes apparently no more than the eighth abdominal segment,

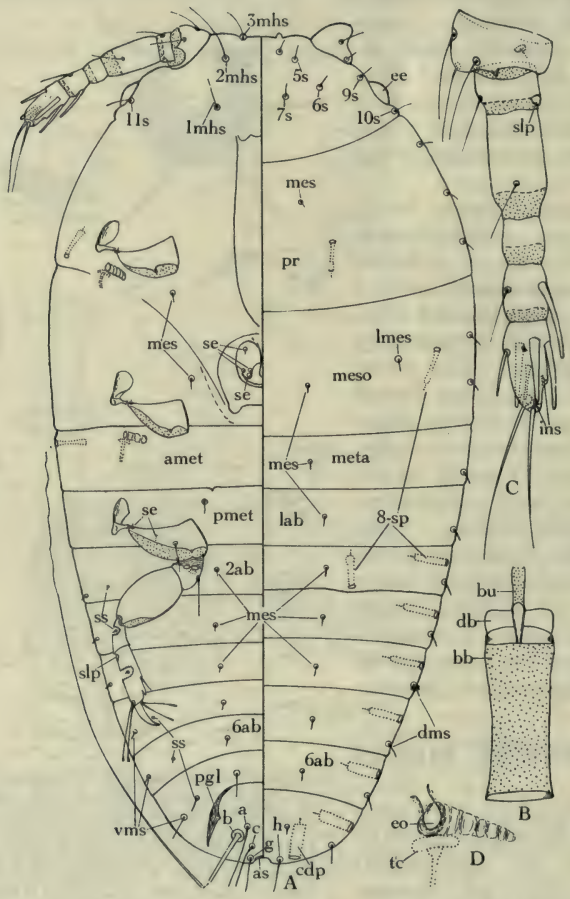


FIGURE 67.—*Ancepaspis edentata*, first-stage nymph: *A*, Body, dorsal and ventral, × 500; *B*, 8-shaped pore, × 3,000; *C*, antenna, ventral, × 1,000; *D*, mesothoracic spiracle, × 2,000.

although it may extend sufficiently cephalad practically to crowd out the dorsomesal part of the seventh or perhaps even the sixth abdominal segment (fig. 48), is always more or less depressed below the surrounding surface, and has its laterocaudal margins sharply defined. With these differences and the apparent presence of one pair of pygidial lobes and possibly the beginnings of a second pair, no other characteristics in this stage of *A. edentata* appear to be noticeably at variance with those in the Phoenicococcini. The adult female of *A. edentata* (figs. 69 and 70) apparently has no characteristics that clearly distinguish it from the Phoenicococcini.

In the related species *Ancepaspis tridentata* (fig. 71), also, the only type of pore observed in the first stage and in the second and adult female stages is the 8-shaped tubular one, which apparently is of the same character as that occurring in *A. edentata* and the Phoenicococcini. In these stages *A. tridentata* differs chiefly from *A. edentata* as follows: First stage with two pairs of anal lobes; second-

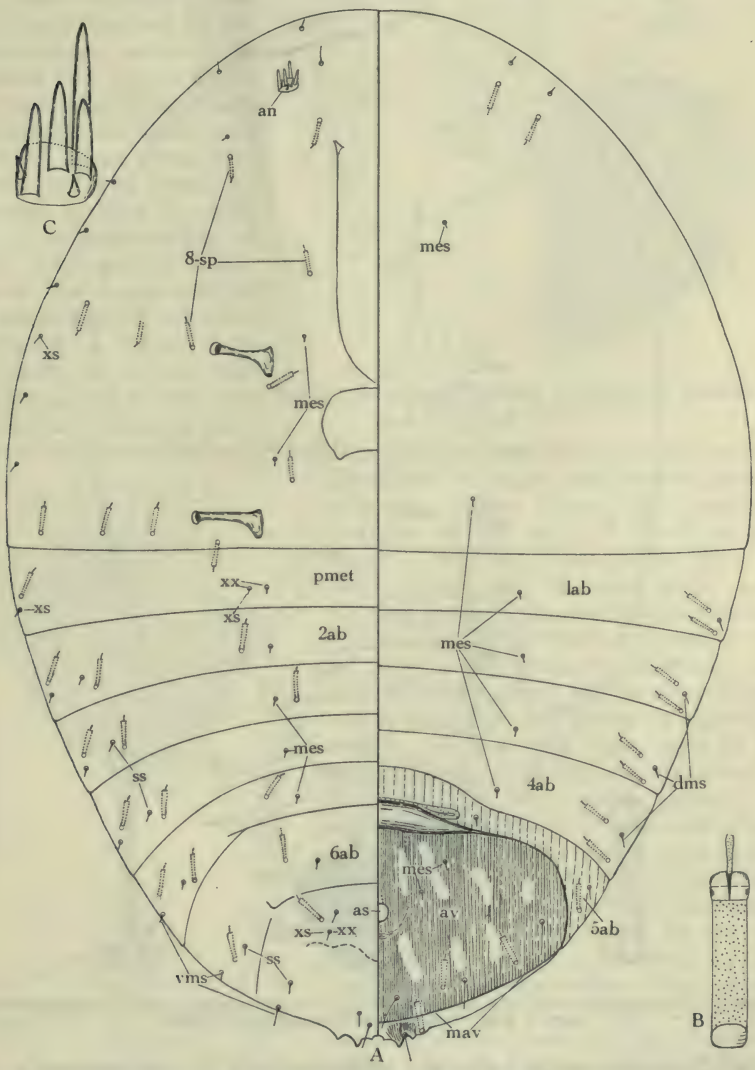


FIGURE 68.—*Ancepaspis edentata*, second-stage female: *A*, Body, dorsal and ventral, × 300; *B*, 8-shaped pore, × 3,000; *C*, antenna, × 2,000.

stage female with a distinct pygidium as far as sclerotization, pores, and setae go, but having no evident lobes or plates, though the undifferentiated caudal end projects to some extent, and no definite anal valve, the region corresponding to the boundaries of this in *A. edentata* having entirely disappeared in this stage, though apparently for egress of the subsequent generation of nymphs an irregular

rupture of the tissue takes place near the laterocaudal margin of the pygidium; adult female having a modification of the posterior end resulting in a pygidium with a characteristic 3-pronged caudal projection.

Both *Ancepaspis edentata* and *A. tridentata* produce a covering of waxy filaments of the same general texture and color as is produced

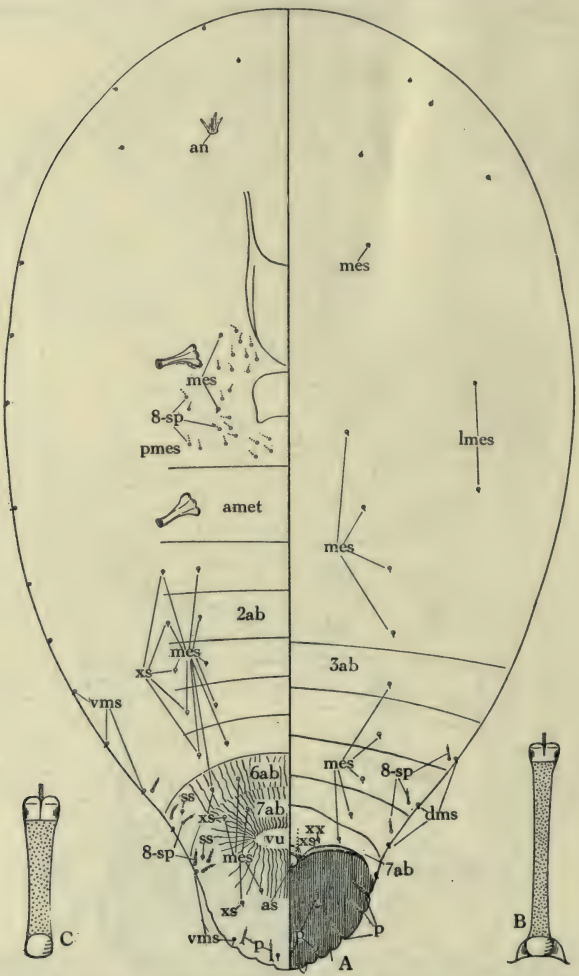


FIGURE 69.—*Ancepaspis edentata*, adult female: *A*, Body, dorsal and ventral, × 250; *B*, marginal 8-shaped pore, × 3,000; *C*, midventral 8-shaped pore, × 3,000.

in the Phoenicococcini; also the adult male of *A. tridentata* (fig. 72) (that of *A. edentata* was unavailable) is strikingly like those of the Phoenicococcini in that it develops in a definite first-stage puparium, has no vestige of wings or thoracic wing framework, and has a pronounced antennal club, stocky legs, and a rapierlike posterior projection. No specimens of the second-stage male of either *A. edentata* or *A. tridentata* were available.

In the second and adult female stages of *Protodiaspis lagunae* Ferris and *P. agrifoliae* Essig the pores are distinctly 8-shaped, numerous, scattered, all small, and structurally of the types (except in size and shape) figured for the second-stage male of *P. lagunae* (fig. 73, *A*, *B*, *D*, *E*). Apparently the only real structural difference between these pores and those in *Ancepaspis edentata* is that a sufficient sclerotization of what is apparently a section of the upper ends of the membranous tube has produced a third bar. The pores of the second-stage male of these two species are numerous, mostly of the small type figured for *P. lagunae*, but in the latter there are five pairs of large, very broad, heavily sclerotic pores along the posterior margin, of the type of the large pore figured, and in *P. agrifoliae* there are only three pairs of these large pores in this stage. In *Ancepaspis anomala* Green (fig. 73, *G*) this large, heavy type of pore is numerous posteriorly and around the margin in the second-stage male, but does not occur in any other stage. In the first stage and in the second and adult female stages of *A. anomala* the only pores present are structurally (except in size and shape) on the order of the large type figured for the first stage of *Chionaspis etrusca* Leon. (fig. 76, *B*), but all are small, numerous, and scattered in the two later female stages mentioned, as in *P. lagunae* and *P. agrifoliae*. In *C. etrusca* (fig. 76, *C* and *E*) a large heavy pore is in evidence, not only in the second-stage male, but in the second and adult female stages. It is a characteristic type in the corresponding stages of all typical diaspids. Viewed endways, these large heavy pores exhibit a typical twisted 8-shaped effect. The only other pore types present in any stage of *P. lagunae*, *P. agrifoliae*, and *A. anomala* are trilocular or quinquelocular disk ones, the pores of which are

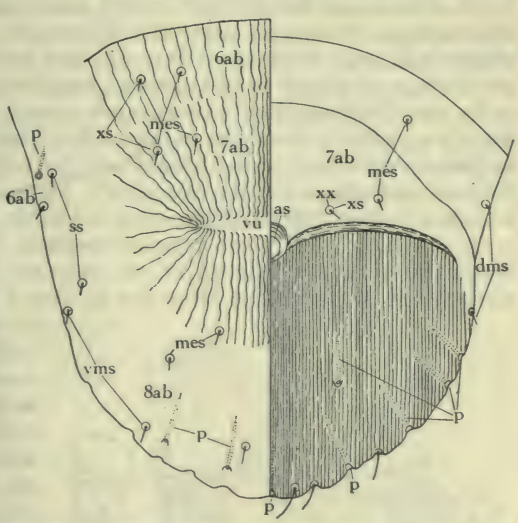


FIGURE 70.—*Ancepaspis edentata*, adult female, posterior end, dorsal and ventral, × 550.

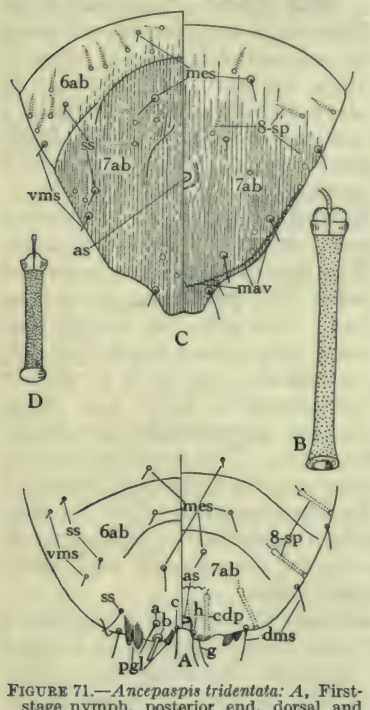


FIGURE 71.—*Ancepaspis tridentata: A*, First-stage nymph, posterior end, dorsal and ventral, × 500; *B*, same, marginal 8-shaped pore, × 3,000; *C*, second-stage female, posterior end, dorsal and ventral, × 500; *D*, adult female, 8-shaped pore, × 3,000.

associated with one or both pairs of spiracles only. *P. lagunae* is of further interest in that its adult male is noticeably like those in *Ancepaspis tridentata* and the Phoenicococcini, the antenna being about half way between being clubbed and filiform and there being no vestige of wings or of thoracic wing framework.

In the first stage of *Ancepaspis anomala* the posterior end is distinctly pygidial, the anus being well up on the dorsal surface, which is plainly sclerotic, and at least one pair of pygidial lobes is present. The second-stage female becomes a puparium, but the caudal valve, which is better defined than in *A. edentata*, is entirely on the ventral surface though the anus remains normal in position on the dorsum. Both the anus and the valve are apparently restricted to the eighth abdominal segment, as they are in the Phoenicococcini. The adult male of *A. anomala* has along filiform antenna and well-developed thoracic wing framework and wings. These features, taken in conjunction with the typical diaspid type of tubular pore in the first stage and the second and adult female stages, indicate this species to be quite different from *A. edentata* and *A. tridentata*.

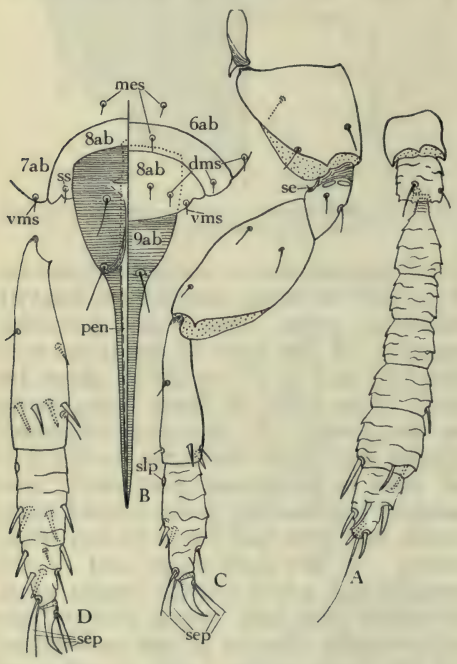


FIGURE 72.—*Ancepaspis tridentata*, adult male: *A*, Antenna; *B*, posterior end, dorsal and ventral; *C*, mesothoracic leg; *D*, tibiotarsus of metathoracic leg. × 500.

Full figures are given for the first stage and the second-stage female of *Chionaspis etrusca* (figs. 74 and 75) in order to show the structural parts in a typical diaspid. In both stages most of the body parts can apparently be readily homologized with the corresponding ones in the Phoenicococcini. The tubular pores are 8-shaped, with the partition extending only through the distal bar; they are of two kinds (fig. 76, *A* and *B*), one with a wholly membranous tube, the other having apparently developed a sclerotic bar in the upper part of the tube. The smaller tubular pore and also the heavy type of tubular pore in the adult female of *C. etrusca* (fig. 76, *D* and *E*) appear to be fundamentally like those in the adult female and second-stage male, respectively, of species in *Protodiaspis* mentioned above. The pores of the second and adult female stages of *C. etrusca* are essentially alike.

The antenna of the first stage of *C. etrusca* has only five segments and one slender seta on the distal segment, but otherwise it bears a near resemblance to the 6-segmented type in the Phoenicococcini. In an aspidiotine form the only noteworthy differences between its annulated type of antenna and that present in a genus of the Phoenicococcini (fig. 52) are the presence of an additional seta on the

basal segment, the absence of 2 or 3 setae on the annulated part, and possibly the sharper outlines of the third and fourth segments.

The dried material of *Xanthophthalma concinnum* Cockerell and Parr resembles that of the diaspid type. The adult female, for example, possesses two naked exuviae attached to a thin waxy shell entirely covering the body. The first stage and the adult female stage of *X. concinnum* (figs. 77 and 78) apparently possess only one type of pore, the 8-shaped tubular one, which seems to have the essential characteristics of that type in the Phoenicococcini except that a slight sclerotization, apparently of the membranous tube, just below the bar can be distinguished in at least the first stage. This pore is apparently not essentially different from a type occurring in the second-stage male of *Ancepaspis anomala* Green (fig. 73, *H*), or even in a more typical diaspine form (fig. 73, *I* and *K*). *X. concinnum* is included in this discussion because it shows some definite diaspid characteristics such as those mentioned above but has some others not so definitely diaspidlike, for example, an ill-defined pygidium, if this structure can be considered as present at all, in both of the above-mentioned stages, in which segmentation is complete through to the eighth abdominal segment, no clear-cut sclerotic piece or pygidial lobes or plates, and no accumulation of distinctly specialized pores in the posterior region.

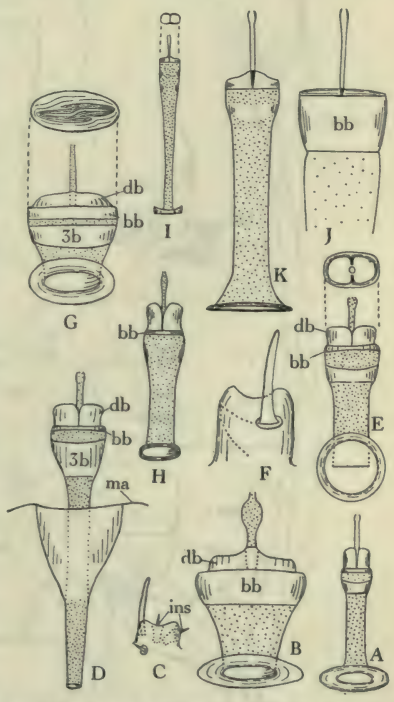


FIGURE 73.—*A–F, Protodiaspis lagunae: A*, Second-stage male, smaller pore, × 3,000; *B*, same, heavy posterior marginal pore, × 3,000; *C*, same, antenna, × 2,000; *D*, adult female, raised pore, × 3,000; *E*, same, pore, × 3,000; *F*, same, antenna, × 2,000. *G* and *H*, *Ancepaspis anomala: G*, Second-stage male, heavy posterior marginal pore, × 3,000; *H*, same, cephalic marginal pore, × 3,000. *I–K*, *Aspidiotus* sp.: *I*, First-stage nymph, 8-shaped pore, × 3,000; *J*, adult female, section of very long caudal pore, × 3,000; *K*, same, moderate-sized marginal pore, × 3,000.

A word as to the anal valve. Between its type in the Phoenicococcini and that in *Ancepaspis edentata* there would seem to exist a gulf, owing to the larger number of segments embraced by the anal valve in the latter. Yet in *A. anomala*, a species that has more typical diaspid characteristics than its congener *A. edentata*, and, for example, in *Gymnaspis ramakrishnae* Green, a rather definite diaspid, the valve embraces no more segments than in species of the Phoenicococcini, and is, moreover, entirely on the ventral surface, thus being decidedly different in this particular from *A. edentata* and the Phoenicococcini. On the other hand, from the type of anal valve in *A. edentata* to the lack of one in *A. tridentata*, in which species, however, the tissue eventually ruptures along a rather definite, though irregular line, appears to be only a simple step, and continuing to the pygidium of the corresponding stage of a typical diaspid, as, for example, *Chionaspis*

*etrusca* Leon. (fig. 75), appears to be only another step. However, it must not be assumed that the pygidium necessarily developed in this manner, since a pygidium, or at least a posterior rather clearly

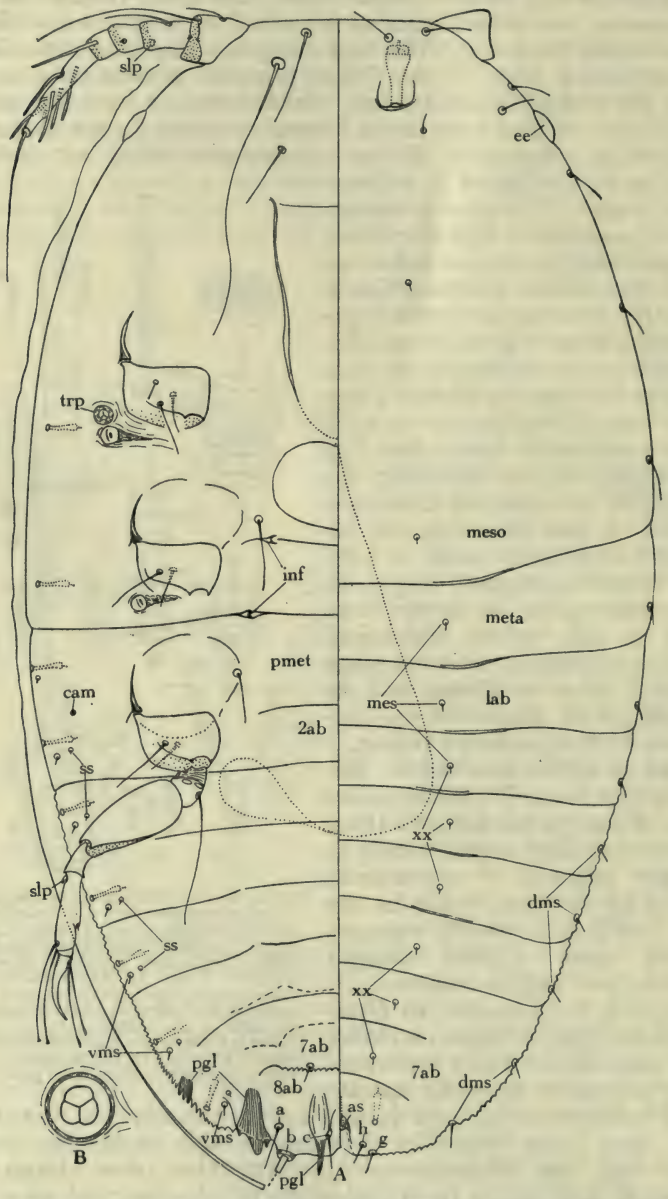


FIGURE 74.—*Chionapsis etrusca*, first-stage nymph: *A*, Body, dorsal and ventral, × 600; *B*, trilocular mesothoracic pore, × 2,000.

defined sclerotic dorsocaudal area possessing pores, setae, and the anus, and in one species pygidial plates as well, is present in the adult female of members of the Phoenicococcini. In some species of this

tribe, also in *A. edentata* and *A. tridentata*, the pygidium appears to include no more than the dorsum of the eighth abdominal segment, but in other species (figs. 54 and 60) it appears to embrace or crowd out, also, at least parts of the dorsum of the seventh and even the sixth abdominal segment, thus approaching the condition in typical

FIGURE 75.—*Chionaspis etrusca*, second-stage female: *A*, Body, dorsal and ventral, × 500; *B*, antenna. × 2,000.

diaspids, in which this structure is considered to embrace ordinarily all of the eighth, seventh, and sixth abdominal segments. Since the characteristics exhibited by the valve and the pygidium are shown to be independently variable, even among definitely related species, it would seem that differences in the value between such a species as

*A. edentata* and the Phoenicococcini should not be considered of serious moment.

A theory of the evolution of the 8-shaped tubular pore occurring among the more typical diaspids may be presented very briefly as follows: At first (as in *Ancepaspis edentata* and *A. tridentata*) the pores are subequal and moderate in size in all stages. They possess two bars, a bulla, and a regular 8-shaped effect, and have the partition extending no more than through the distal bar. In short, they are in general character like the more delicate pores occurring in members of the Phoenicococcini. Eventually certain modifications arise. An apparent third bar begins to form in some pores, either out of the basal bar or out of the upper part of the membranous tube. This third bar may or may not become strongly sclerotic and well defined. At the same time a tendency may or may not develop for the pores, especially the marginal ones, to increase in size and sclerotization, becoming the heavy pores mentioned above as present in various diaspids, including the typical one, *Chionaspis etrusca*, represented here.

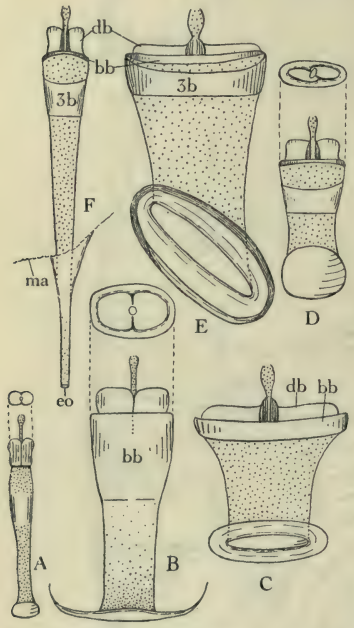


FIGURE 76.—*Chionaspis etrusca*: *A*, First-stage nymph, 8-shaped pore; *B*, same, large head pore; *C*, second-stage male, heavy posterior marginal pore; *D*, adult female, smaller pore; *E*, same, heavy posterior marginal pore; *F*, same, raised pore, ×3,000.

*Ancepaspis edentata*, as has been brought out, shows more characteristics in common with the Phoenicococcini than does any other species studied. With differences between its anal valve and those of the Phoenicococcini indicated as being unimportant, this species is sufficiently similar to the Phoenicococcini in its general characteristics to be considered as related to this tribe. *A. tridentata*, without doubt congeneric with *A. edentata*, reveals only a little less in common with the Phoenicococcini than does *A. edentata*. Since these two species have definite diaspine features, such as pygidial lobes in the first stage and a pygidial posterior end in both the second stage female and the adult female, and have, moreover, no characteristics that would eliminate them from the diaspine assemblage, there seems to be sufficient justification for not only allying the Phoenicococcini with the diaspines but even including them within that assemblage.

Since *Ancepaspis edentata* and *A. tridentata* show possibly more characters in common with the Phoenicococcini than they do with any other species studied, it seems reasonable to suggest that these two species might properly be placed in a separate tribe to be included in the new subfamily Phoenicococcinae. Were this done, the definition of this subfamily as given herein would naturally have to be revised. However, no more than a suggestion for this classification

of these two species will be made in this bulletin, and no suggestions will be offered toward the segregation of other diaspid species studied.

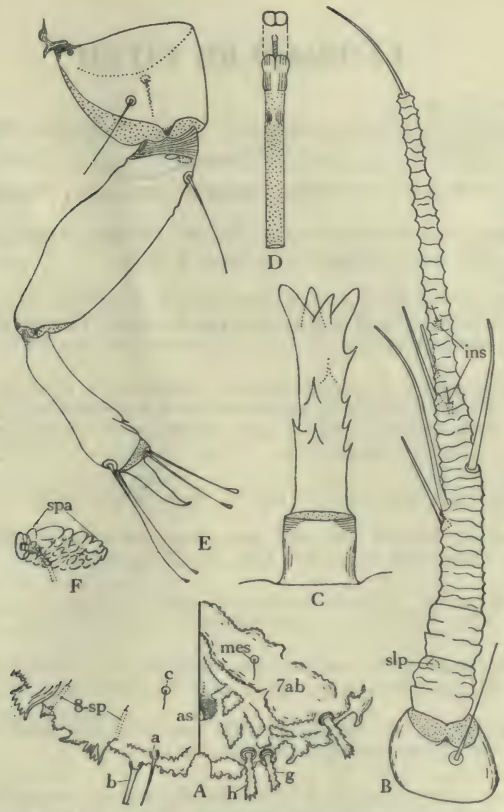


FIGURE 77.—*Xanthophthalma concinnum*, first-stage nymph: *A*, Posterior end, dorsal and ventral, × 500; *B*, antenna, × 1,000; *C*, branched marginal seta, × 2,000; *D*, 8-shaped pore, × 3,000; *E*, metathoracic leg, × 1,000; *F*, mesothoracic spiracle, × 1,000.

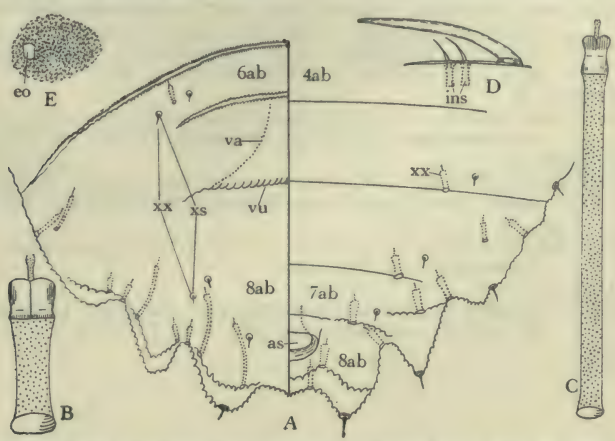


FIGURE 78.—*Xanthophthalma concinnum*, adult female: *A*, Posterior end, dorsal and ventral, × 500; *B*, shorter 8-shaped pore, × 3,000; *C*, elongated posterior marginal 8-shaped pore, × 3,000; *D*, antenna, × 2,000; *E*, mesothoracic spiracle, × 500.

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TECHNICAL BULLETIN No. 403 FEBRUARY 1934

# HYDRION CONCENTRATION CHANGES IN RELATION TO GROWTH AND RIPENING IN FRUITS

BY

JOSEPH S. CALDWELL

Senior Physiologist

Division of Fruit and Vegetable Crops and Diseases
Bureau of Plant Industry

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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*Senior physiologist Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry*

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## INTRODUCTION

The investigation of methods of preserving fruits now in progress in the fruit and vegetable utilization laboratory of the Bureau of Plant Industry has necessarily involved a study of the chemical and physicochemical methods of determining the stage of maturity of the fruit, since the stage of maturity of the material largely determines the quality of the preserved product. A rather extensive study has been made of the changes occurring in the hydrion concentration of the juices of ripening fruits, in order to determine whether the hydrion concentration of the juice is in any degree a dependable criterion of the stage of maturity. Since May 1927 this study has been supplemented by an investigation designed to secure a somewhat fuller knowledge of the nature and extent of the changes in active and titratable acidity of the fruit juices in the earlier stages of development. Comparative studies have been made of the relations between changes in active acidity, on the one hand, and changes in volume or weight and in chemical composition, on the other hand, in a number of fruits of widely diverse character, representing widely separated botanical groups. This bulletin reports the results of these studies.

## REVIEW OF LITERATURE

A number of workers have recently reported results of determinations of hydrion concentration or titratable acidity, or both, made upon developing fruit. These data collectively indicate that both

[1] The writer gratefully acknowledges his indebtedness to Byron C. Brunstetter, for assistance in making many of the hydrion determinations, and to C. W. Culpepper and H. H. Moon, for assistance in the chemical analyses.

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active and total titratable acidity increase as growth advances, attain a maximum about the time ripening begins, and then decrease as ripening proceeds.

Bartholomew (*4*) [2] appears to have been the first worker to call attention to the large change in hydrion concentration occurring in the juice of a fruit during its period of development. He made determinations of average diameter, water content, and hydrion concentration upon Eureka lemons at Riverside, Calif., at intervals of 1 month from September 10 to July of the following year. There was an increase in active acidity from pH 4.46 to 2.30 (0.000034N to 0.005N)[3], or to an active acidity 144 times as great as that of the initial sample, occurring in the course of 10 months of growth. Of this total, the change from pH 4.46 to 2.91, representing an increase in active acidity of more than thirty-fivefold, occurred in 2 months, and was accompanied by an increase in water content from 53.9 to 81.4 percent and an increase in volume of about 350 percent. Bartholomew has not given the results of determinations of titratable acidity and average weight of fruits and made no determinations of titratable or active acidity upon the wood or leaves of his trees. Reed and Halma (*29*) made determinations of hydrion concentration values upon sap of fruiting wood and shoot wood of 3-year-old and 8-year-old lemon trees at intervals throughout the year and found an approximately fivefold increase in active acidity in the vegetative tissues in the course of the season.

Oppenheim and Winik (*25*), working at the Palestine Agricultural Experiment Station, followed the changes in sugar content and hydrion concentration in the Jaffa orange throughout its development. Determinations of hydrion concentration were begun on July 1 and continued at 2-week intervals until March 1, the fruit becoming fit for shipment or consumption about December 1. Beginning with pH 4.4 (0.000039N) on July 1, there was a progressive change to pH 2.8–3.0 (0.00158N–0.001N) on October 1. After this date there was a further change to a value of pH 3.5 (0.000316N) on March 1. Increase in sugar content began October 15 and continued until January 1, after which it fluctuated without definite change. Neither acidity nor sugar changes could be correlated with the occurrence of the rainy season or with other meteorological factors.

Alwood and his collaborators (*1*) showed that there is a large decrease in total titratable acidity in grapes during coloration and ripening, because of progressive conversion of free tartaric acid into acid potassium tartrate. Copeman (*9*, *10*, *11*) and Copeman and Frater (*12*) studied the changes in active and in total acidity throughout the larger portion of the period of development and found that both increased to a maximum during growth, then decreased as the fruit ripened.

Gustafson (*16*, *18*), working at Ann Arbor, Mich., studied the rate of increase in volume and green weight and the change in percentage of dry matter in two varieties of tomatoes at weekly intervals from blooming to ripeness. Titratable acidity and hydrion concentration were determined at weekly intervals and showed very little change

[2] Italic numbers in parentheses refer to Literature Cited, p. 51.

[3] In order to facilitate comparisons of active acidity values, statements of values in terms of the pH scale are followed in parentheses by their equivalents in terms of a normal solution of hydrogen ions, i.e., in terms of $C_H$. Similar values for the upper and lower limits of active acidity encountered in the material appear in the tables.

from the first to the third week. During the fourth and fifth weeks, however, there was a shift of hydrion concentration from about pH 4.70 to 4.30 (0.0000199N to 0.0000501N), accompanied by an increase of approximately 50 percent in titratable acidity. This was the period of most rapid growth, the fruits increasing about 300 percent in weight and in volume during this time (*17*). After the fifth week there was a slow increase in both active and titratable acidity, which reached a maximum about the time the fruit ceased to enlarge and some specimens had begun to turn color (*19, p. 354*). From this point onward titratable and active acidity declined somewhat irregularly until the fruit was ripe. The results in regard to the decrease in titratable acidity with advance in age are in agreement with those of Sando (*35*). The work of Rosa (*32, 33*) dealt with changes in ripening tomatoes and that of Appleman and Conrad (*3*) and MacGillivray and Ford (*23*) with the hydrion-concentration relations in the ripe fruit. None of these included the earlier stages.

Hartman and Bullis (*20*) found a slight but progressive decline in both titratable and active acidity in several varieties of cherries as the fruit passed from immaturity through ripeness to a decidedly overripe condition. Neller and Overley (*24*) and St. John and Morris (*34*) found a similar decline in titratable and active acidity in apples during the last 7 or 8 weeks on the tree; most of the decrease occurred in a relatively short period just before the fruit reached picking maturity. Overholser (*26*) found that pears showed a progressive increase in active acidity from the time the fruits had one twelfth to one sixth the mature weight until they approached shipping ripeness, when active acidity became stationary or decreased slightly.

The results of the workers just cited indicate that in the lemon, the orange, the pear, and the tomato there is a rather marked rise in active acidity throughout the period of rapid growth, which reaches a maximum about the time growth is completed and ripening processes set in and which is followed by a more or less pronounced decline as ripening proceeds. In the cherry, the grape, and the apple the available data do not cover the early stages of development, but the detailed studies of the later portion of the life period in these fruits show that the changes in active acidity follow a like course. It is also clearly indicated that in fruits, as in vegetative parts (*15*), there is no constant relation between total and active acidity values, and only the broadest general parallelism in their changes.

A number of workers have given more or less attention to the changes in water content occurring in fruits during development. Bartholomew (*4*) has shown for lemons and Gustafson (*18*) for tomatoes that during the earlier stages of growth there is a progressive and in the aggregate a rather large increase in water content, which slows down as the fruit approaches maturity.

Bartholomew (*5*) has directed attention to the fact that in citrus fruits there may be a withdrawal of water from the fruit by the leaves at almost any period in the life of the fruit. In periods of high transpiration this may result in loss of turgor in the afternoon, with recovery during the night; in periods of prolonged drought it may result in the withdrawal of such a quantity of water as to bring about the collapse and breaking down of the tissues adjacent to the vascular bundles (internal decline). Reed (*27*) has further emphasized the existence of an equilibrium of water between tree and fruit, and has

demonstrated the existence of a large saturation deficit in oranges and lemons, as a result of which they swell rather rapidly when placed in water, dilute acid or alkali, or solutions of salts such as calcium chloride or copper sulphate. Reed has further shown that this swelling is due chiefly to imbibition of liquid by the hydrophilic colloids of the mesocarp, but that the juice sacs making up the locules of the fruit have sufficient suction pressure to draw water from the mesocarp. Furr and Magness (*14*) measured the rate of growth in the fruit of apples on irrigated and nonirrigated plots and found that in the apple decrease in soil moisture content nearly to the wilting coefficient resulted in cessation of growth of the fruit and in some cases [4] in an absolute decrease in volume. H. H. Moon, in studies on peaches in progress in this laboratory, found that in a period of severe drought the young fruit first slowed down in rate of growth, reached a standstill, and then shrank in size, the reduction involving all three diameters of the fruit.

It is evident that in the peach and apple, as in the citrus fruits, there is an equilibrium in water content between fruit and vegetative parts and that under conditions of insufficient moisture supply movement of water into the fruit may slow down, stop, and ultimately reverse its direction.

## MATERIALS AND METHODS

The work herein described was begun early in 1927. At that time the work of Bartholomew upon the lemon (*4*) was the only report to be found in the literature upon the changes in hydrion concentration occurring in a fruit throughout the whole course of its development. The absence of similar information with respect to the early stages of development in other fruits prompted the present investigation and determined its scope. Its purpose was to determine whether changes in degree of active acidity occurring during the development of fruits follow any definite course, whether the course of such changes is similar in fruits of dissimilar character, and whether such changes are definitely correlated with increase in weight and volume and with changes in chemical composition during growth and ripening. It was therefore planned to make a rather detailed study of the apple, cherry, strawberry, tomato, orange, and grapefruit, employing where possible a number of horticultural varieties of each fruit. Material for determinations of weight, moisture content, active acidity, and chemical composition was collected at predetermined intervals throughout the course of development, beginning as soon as the fruit had set. For the purpose of gaining knowledge of the general course of changes in active acidity during growth in fruits of some other types, a less detailed study was made of the blackberry, raspberry, pokeberry (*Phytolacca americana* L.), and elderberry (*Sambucus canadensis* L.).

The general method employed in preparing material for determinations of hydrion concentration was that of grinding the fruit, after removal of the seed and peel, through a food chopper equipped with a pulverizing disk, pressing the juice from the pulp through muslin in a small tincture press or by hand, and filtering or centrifuging, where necessary, to remove cellular debris. In the case of very

[4] Personal communication from J. R. Magness.

small samples the material was ground as thoroughly as possible with a porcelain mortar and pestle and expressed by hand. That the juices obtained by the use of a press and those expressed by hand were identical in their hydrion concentration was determined by numerous checks.

The hydrion-concentration determinations in all cases were begun within 5 to 10 minutes, usually within a shorter time, after the juice had been expressed. Simultaneous determinations were made, with certain exceptions noted hereafter, by means of a hydrogen electrode of the Bailey type and a quinhydrone electrode, the latter being used as a comparison electrode. In the majority of the fruits examined readings with the two electrodes agreeing within 0.05-0.07 pH were readily obtainable and the agreement was frequently within 0.03 pH. The juices of some fruits contain substances that react with quinhydrone, producing a drift of potential which makes the quinhydrone electrode unreliable in dealing with them. For some of these the hydroquinhydrone electrode was employed as a comparison electrode with satisfactory results; for others it was useless. The Hildebrand hydrogen electrode was used in some instances. In the case of very small fruits or limited amounts of material the modification of the Bodine and Fink microelectrode described by Brunstetter and Magoon (*6*) was employed after its development in 1928. As pointed out by these authors, the microelectrode may be employed both as a hydrogen and as a quinhydrone electrode, and was so used in some instances to obtain duplicate readings upon small samples. The rapidity with which several determinations could be made permitted its use as a check on the Bailey hydrogen electrode in such juices as could not be dealt with by the quinhydrone method. Some use of colorimetric methods was made for the purpose of determining the degree of accuracy obtainable with such methods upon the material in hand.

The samples for the chemical analyses were in all cases taken from the same lot of material employed for the hydrion-concentration determinations. Duplicate samples of 40 to 100 g of the finely minced material were weighed out, placed in sufficient 95 percent alcohol to make the alcohol concentration at least 80 percent, and heated to boiling. After some 6 to 8 months storage the extraction was completed by extraction with fresh 95 percent alcohol for 6 to 10 hours in Soxhlet extractors. The various determinations were made upon aliquots of the alcohol extract by the standard methods of the Association of Official Agricultural Chemists.

## ANALYTICAL RESULTS

### APPLES

Preliminary studies on apples were made in 1927 and more intensive studies in 1928 and 1929. Eight varieties were employed. These were chosen to represent a fairly wide range in chemical composition and length of developmental period, and included the standard varieties Baldwin, Grimes Golden, and Paragon; the summer varieties Williams and Rambo; the highly astringent French apples Launette and Amère du Surville, of the class termed by French pomologists the "douce-amère" group; and *Malus angustifolia* Mich., a native crab species having such exceptionally high acidity and

astringency that the fruit is inedible. In 1929 the absence of a crop of Amère du Surville, Paragon, and Williams reduced the number of varieties employed in that year to five.

Sampling was begun as soon after blooming as it was possible to feel reasonably certain that the fruits selected had begun normal development. This was a matter of some difficulty, since dropping continues through the period in which the young fruits remain practically stationary in size and is often severe after they have begun to enlarge. The trees were inspected almost daily from full bloom onward, and sampling of a variety was begun only when it became apparent that dropping of that variety had practically ceased. In Baldwin and Paragon in 1928 and in Launette and *Malus angustifolia* in 1929, persistent dropping postponed beginning of sampling until the fruits averaged 1 g or more in weight, 15 to 21 days after full bloom; with these exceptions, cessation of dropping allowed sampling to begin when the fruits averaged considerably less than 1 g in weight and were only 8 to 12 days old.

The data obtained in 1928 are assembled in table 1; those secured in 1929 in table 2. The 1927 results were confirmed in all respects by those of the subsequent years but were less complete and are therefore omitted.

TABLE 1.—*Changes in hydrion concentration, weight, and chemical composition of 8 apple varieties throughout development in 1928*

| Variety | Date | Average diameter | Average weight | Active acidity | | Titratable acidity | Sugar | | | Astringent substances | | Solids | | | Water as percentage of total solids | Increase in weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | pH | CH | | Reducing | Sucrose | Total | Tannin | Non-tannin | Soluble | Insoluble | Total | | |
| | | *Mm* | *Grams* | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Amère du Surville | May 18 | 4–7 | 0.402 | 4.73 | 0.00001862N | | | | | | | | | | | |
| | do | 8–11 | .903 | 4.43 | | 0.780 | 1.27 | 0.50 | 1.77 | 2.508 | 1.052 | 8.32 | 8.814 | 17.13 | 483.7 | |
| | May 29 | 16–20 | 2.08 | 3.82 | | .705 | 2.73 | .43 | 3.16 | 3.060 | 1.275 | 9.56 | 5.886 | 15.44 | 547.6 | 130.3 |
| | June 6 | 20–27 | 8.33 | 3.54 | | .692 | 4.95 | 1.11 | 6.06 | 2.860 | .995 | 8.76 | 5.711 | 14.47 | 591.1 | 300.4 |
| | June 14 | 24–32 | 12.75 | 3.43 | .0003715N | .658 | 3.64 | .46 | 4.10 | 2.250 | .810 | 8.08 | 6.319 | 14.40 | 594.4 | 53.0 |
| | June 25 | 29–36 | 19.83 | 3.59 | | .520 | 4.17 | .68 | 4.85 | 2.050 | .638 | 8.32 | 7.399 | 15.72 | 536.7 | 55.5 |
| | July 11 | | 27.88 | 3.77 | | .462 | 2.40 | 2.28 | 4.68 | 1.375 | .500 | 9.12 | 7.730 | 16.85 | 493.5 | 40.5 |
| | July 25 | 40–48 | 38.66 | 3.80 | | .390 | 5.53 | .31 | 5.84 | 1.160 | .485 | 8.80 | 8.204 | 17.00 | 488.2 | 38.6 |
| | Aug. 8 | 40–46 | 51.40 | 3.80 | | .380 | 5.66 | 1.20 | 6.86 | 1.027 | .315 | 9.24 | 7.417 | 16.65 | 500.0 | 32.9 |
| | Aug. 28 | 45–63.5 | 66.66 | 3.77 | | .325 | 5.94 | 1.56 | 7.50 | .820 | .262 | 9.56 | 6.296 | 15.86 | 530.5 | 29.6 |
| | Sept. 24 | | 95.29 | 3.80 | | .315 | 6.84 | 2.30 | 9.14 | .690 | .228 | 10.88 | 4.362 | 15.24 | 566.1 | 42.8 |
| Baldwin | May 17 | 11–13 | 1.77 | 3.35 | .0004467N | 1.173 | 1.26 | .93 | 2.19 | .547 | .260 | 6.72 | 5.730 | 12.45 | 703.2 | |
| | May 22 | 15–18 | 3.00 | 3.28 | | 1.220 | 1.00 | .86 | 1.86 | .476 | .224 | 7.80 | 4.936 | 12.73 | 685.5 | 69.4 |
| | May 31 | 19–25 | 7.69 | 3.02 | | 1.469 | 2.26 | .77 | 3.03 | 1.005 | .348 | 7.24 | 4.994 | 12.23 | 717.6 | 156.3 |
| | June 7 | 23–30 | 14.71 | 2.89 | .001288N | 1.455 | 2.17 | .95 | 3.12 | .584 | .214 | 7.72 | 4.751 | 12.47 | 701.9 | 91.2 |
| | June 14 | 30–35 | 17.85 | 2.91 | | 1.370 | 3.05 | .67 | 3.72 | .532 | .218 | 7.88 | 5.347 | 13.22 | 656.4 | 21.3 |
| | June 27 | 35–42 | 33.39 | 2.95 | | 1.105 | 3.22 | 1.31 | 4.53 | .396 | .164 | 7.44 | 6.415 | 13.85 | 622.0 | 87.0 |
| | July 13 | 38–53 | 59.50 | 3.09 | | .900 | 3.82 | 1.57 | 5.39 | .288 | .126 | 7.68 | 7.914 | 15.59 | 541.4 | 78.2 |
| | July 26 | | 72.06 | 3.15 | | .804 | 4.36 | 1.66 | 6.02 | .208 | .087 | 8.60 | 7.632 | 16.23 | 516.0 | 21.1 |
| | Aug. 10 | 54–63 | 105.71 | 3.15 | | .775 | 4.30 | 1.82 | 6.12 | .288 | .094 | 8.32 | 6.013 | 14.33 | 597.8 | 46.7 |
| | Aug. 28 | 56–74 | 141.54 | 3.14 | | .622 | 4.84 | 1.87 | 6.71 | .227 | .079 | 8.64 | 5.964 | 14.60 | 584.8 | 33.9 |
| | Sept. 24 | | 173.12 | 3.26 | .0005495N | .645 | 5.85 | 4.01 | 9.86 | .176 | .047 | 11.52 | 4.520 | 16.04 | 523.4 | 22.3 |
| Grimes Golden | May 18 | 7–11 | .641 | 3.62 | .0002399N | 1.084 | .68 | .60 | 1.28 | .792 | .356 | 6.64 | 8.238 | 14.87 | 572.5 | |
| | May 29 | 20–18 | 4.00 | 3.12 | | 1.435 | 2.15 | .82 | 2.97 | 1.554 | .248 | 7.60 | 5.667 | 13.26 | 654.1 | 525.0 |
| | June 6 | 20–23 | 8.33 | 2.98 | | 1.290 | 2.47 | .70 | 3.17 | 1.086 | .314 | 6.96 | 6.013 | 12.97 | 671.0 | 108.2 |
| | June 14 | 23–30 | 13.00 | 2.87 | .001349N | 1.220 | 3.30 | .96 | 4.26 | .956 | .580 | 8.40 | 7.308 | 15.70 | 536.9 | 56.0 |
| | June 25 | 30–36 | 23.43 | 2.97 | | 1.036 | 3.04 | 1.38 | 4.42 | .627 | .262 | 7.44 | 7.815 | 15.25 | 555.7 | 80.2 |
| | July 9 | 33–38 | 35.16 | 3.07 | | .840 | 4.47 | 1.71 | 6.18 | .378 | .132 | 8.68 | 9.310 | 17.99 | 455.9 | 50.0 |
| | July 29 | | | 3.20 | | .720 | 4.61 | 2.19 | 6.80 | .295 | .119 | 8.80 | 7.481 | 16.28 | 514.2 | |
| | Aug. 3 | | | 3.24 | | .720 | 4.80 | 2.48 | 7.28 | .209 | .020 | 9.48 | 8.793 | 18.27 | 447.3 | |
| | Aug. 21 | 43–62 | 84.37 | 3.30 | | .620 | 5.76 | 2.50 | 8.26 | .190 | .079 | 10.52 | 7.380 | 17.90 | 457.0 | |
| | Sept. 24 | | 123.75 | 3.54 | .0002884N | .510 | 6.11 | 5.61 | 11.72 | .196 | .072 | 13.28 | 3.915 | 17.19 | 481.7 | |
| Launette | May 18 | 5–7 | .348 | 4.79 | .00001622N | .900 | .80 | 1.10 | 1.90 | 1.821 | .980 | 8.80 | 11.185 | 19.98 | 400.5 | |
| | May 29 | 18–13 | 2.08 | 3.99 | | .764 | 2.46 | .50 | 2.96 | 4.450 | 2.020 | 10.04 | 7.700 | 17.74 | 463.7 | 497.7 |
| | June 6 | 28–19 | 5.26 | 3.75 | | .720 | 3.17 | .05 | 3.22 | 4.450 | 1.610 | 9.88 | 7.806 | 17.68 | 465.6 | 152.8 |
| | June 14 | 30–22 | 9.79 | 3.76 | | .817 | 3.47 | 1.00 | 4.47 | 5.150 | 1.960 | 11.36 | 8.279 | 19.64 | 409.1 | 86.1 |
| | June 25 | 26–37 | 16.66 | 3.72 | .0001905N | .652 | 3.41 | 1.09 | 4.50 | 4.670 | 1.290 | 9.44 | 9.016 | 18.45 | 442.0 | 70.1 |
| | July 11 | | 26.0 | 3.96 | | .552 | 4.47 | 1.41 | 5.88 | 2.670 | 1.007 | 9.72 | 12.418 | 22.14 | 351.0 | 56.0 |
| | July 25 | 35–40 | 35.0 | 4.08 | | .438 | 5.61 | 1.32 | 6.93 | 2.680 | .803 | 10.92 | 11.777 | 22.69 | 340.7 | 34.6 |
| | Aug. 8 | 42–57 | 56.56 | 4.10 | | | | | | | | | | | | 61.6 |
| | Aug. 28 | 48–57 | 68.75 | 4.43 | | .352 | 7.24 | 2.40 | 9.64 | 1.180 | .382 | 12.28 | 6.207 | 18.48 | 441.1 | 21.5 |
| | Sept. 24 | | 81.79 | 4.31 | .00004898N | .325 | 8.28 | 3.36 | 11.64 | .910 | .336 | 13.92 | 4.964 | 18.88 | 429.7 | 18.9 |

TABLE 1.—*Changes in hydrion concentration, weight, and chemical composition of 8 apple varieties throughout development in 1928*—Con.

| Variety | Date | Average diameter | Average weight | Active acidity | | Titratable acidity | Sugar | | | Astringent substances | | Solids | | | Water as percentage of total solids | Increase in weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | pH | CH | | Reducing | Sucrose | Total | Tannin | Non-tannin | Soluble | Insoluble | Total | | |
| | | *Mm* | *Grams* | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Paragon | May 22 | 11–14 | 1.38 | 3.40 | 0.0003981N | 0.682 | 2.19 | 0.39 | 2.58 | 1.510 | 0.700 | 10.24 | 6.206 | 16.44 | 508.2 | |
| | do | 14–17 | 2.44 | 3.29 | | .576 | 1.47 | .77 | 2.24 | 1.137 | .486 | 7.04 | 5.870 | 12.91 | 674.6 | |
| | May 31 | 20–22 | 6.25 | 3.09 | | 1.312 | 2.26 | .87 | 3.13 | 1.472 | .487 | 7.96 | 5.432 | 13.39 | 646.8 | 156.7 |
| | June 7 | 22–28 | 12.50 | 3.00 | .001N | 1.405 | 2.42 | .66 | 3.08 | 1.100 | .395 | 7.32 | 5.165 | 12.48 | 701.3 | 100.0 |
| | June 14 | 27–32 | 17.85 | 3.04 | | 1.210 | 2.87 | .79 | 3.66 | 1.010 | .455 | 7.84 | 5.678 | 13.51 | 647.6 | 42.8 |
| | June 27 | 30–35 | 24.80 | 3.12 | | .915 | 2.82 | .62 | 3.44 | .810 | .286 | 7.60 | 6.706 | 14.30 | 600.0 | 38.9 |
| | July 13 | 38–45 | 37.61 | 3.13 | | .677 | 3.87 | 1.39 | 5.26 | .576 | .193 | 7.64 | 7.993 | 15.63 | 539.7 | 51.6 |
| | July 27 | 38–53 | 55.60 | 3.35 | | .678 | 4.49 | 1.03 | 5.52 | .346 | .196 | 8.12 | 7.749 | 15.87 | 542.6 | 47.8 |
| | Aug. 10 | 42–62 | 76.05 | 3.37 | | .587 | 4.84 | 2.02 | 6.86 | .330 | .134 | 8.48 | 7.049 | 15.53 | 542.8 | 36.7 |
| | Aug. 28 | 49–69 | 100.66 | 3.30 | | .750 | 4.56 | 2.42 | 6.98 | .280 | .062 | 8.92 | 6.577 | 15.49 | 545.5 | 32.3 |
| | Sept. 24 | | 135.50 | 3.37 | | .540 | 5.95 | 2.77 | 8.72 | .210 | .083 | 9.80 | 5.259 | 15.05 | 564.4 | 34.6 |
| Malus angustifolia | May 15 | 3–5, 5–8 | .356 | 4.05 | .00008318N | 1.380 | .65 | 1.00 | 1.65 | 1.688 | 1.110 | 11.60 | 7.675 | 18.27 | 444.3 | |
| | May 29 | 15–12 | 1.85 | 2.97 | | 1.456 | .88 | .82 | 1.70 | 2.405 | 1.290 | 9.32 | 4.715 | 14.03 | 612.6 | 419.7 |
| | June 5 | 16–20 | 3.97 | 2.89 | | 1.476 | .60 | .23 | .83 | 2.305 | .872 | 8.32 | 4.057 | 12.37 | 708.4 | 114.6 |
| | June 18 | | 8.00 | 2.65 | | 1.866 | .66 | .90 | 1.56 | 2.540 | .875 | 9.12 | 5.117 | 14.23 | 602.7 | 101.5 |
| | June 25 | 33–20 | 9.83 | 2.77 | | 1.956 | .81 | .72 | 1.53 | 1.973 | .820 | 7.64 | 5.795 | 13.43 | 646.6 | 22.8 |
| | July 17 | | 16.00 | 2.50 | | 2.390 | .86 | .57 | 1.43 | 2.430 | .580 | 9.16 | 7.285 | 16.44 | 508.2 | 62.7 |
| | Aug. 6 | | 21.36 | 2.62 | | 2.770 | 1.39 | .81 | 2.20 | 2.000 | .405 | 9.44 | 7.308 | 16.74 | 497.4 | 33.5 |
| | Oct. 3 | | 34.80 | 2.42 | .003802N | 2.520 | 2.81 | 1.45 | 4.26 | 1.280 | .374 | 9.92 | 2.994 | 12.91 | 674.6 | 62.9 |
| Summer Rambo | May 18 | 6–9 | .724 | 3.70 | .0001995N | .940 | .70 | .70 | 1.40 | 1.185 | .592 | 7.44 | 8.430 | 15.87 | 530.1 | |
| | do | 10–13 | 1.47 | 3.45 | | 1.360 | .88 | .26 | 1.14 | 1.208 | .515 | 7.14 | 6.704 | 13.84 | 622.0 | |
| | May 31 | 21–25 | 9.80 | 2.97 | | 1.375 | 2.93 | .48 | 3.41 | 1.172 | .394 | 7.84 | 5.376 | 13.21 | 657.0 | 566.6 |
| | June 6 | 25–34 | 18.0 | 2.78 | | 1.435 | 2.67 | .34 | 3.01 | 1.098 | .356 | 6.92 | 5.241 | 12.16 | 722.3 | 83.6 |
| | June 14 | 28–40 | 25.0 | 2.74 | .00182N | 1.175 | 3.57 | .39 | 3.96 | .778 | .222 | 7.16 | 6.122 | 13.28 | 653.0 | 38.8 |
| | June 25 | 32–46 | 41.66 | 2.88 | | .785 | 4.40 | 1.28 | 5.68 | .546 | .208 | 8.16 | 5.181 | 13.34 | 649.6 | 66.6 |
| | July 9 | 45–60 | 61.78 | 3.06 | | .565 | 5.32 | 1.54 | 6.86 | .390 | .137 | 8.88 | 6.225 | 15.10 | 562.2 | 48.3 |
| | July 23 | | 100.42 | 3.16 | | .515 | 6.12 | 1.84 | 7.96 | .291 | .109 | 9.36 | 5.257 | 14.61 | 584.4 | 62.5 |
| | Aug. 3 | | 126.9 | 3.24 | | .425 | 5.33 | 1.79 | 7.12 | .219 | .089 | 8.60 | 5.142 | 13.74 | 627.8 | 26.3 |
| | Aug. 21 | 57–80 | 143.84 | 3.33 | | .409 | 6.84 | 2.20 | 9.04 | .196 | .083 | 10.40 | 4.083 | 14.48 | 590.5 | 13.3 |
| Williams | May 22 | 6–11 | .99 | 3.66 | .0002188N | 1.078 | 1.20 | .26 | 1.46 | .940 | .487 | 7.36 | 6.381 | 13.74 | 627.8 | |
| | do | 11–14 | 1.74 | 3.45 | | .648 | .27 | .53 | .80 | .373 | .184 | 6.72 | 6.806 | 13.52 | 639.6 | |
| | May 29 | 15–20 | 5.55 | 3.15 | | 1.390 | 1.70 | .98 | 2.68 | 1.240 | .288 | 7.48 | 5.155 | 12.63 | 691.7 | 218.9 |
| | June 6 | 26–30 | 12.50 | 2.96 | | 1.315 | 2.36 | .76 | 3.12 | .940 | .486 | 6.96 | 4.701 | 11.66 | 757.6 | 125.2 |
| | June 14 | 28–40 | 25.00 | 2.92 | .001202N | 1.210 | 3.37 | 1.07 | 4.44 | .650 | .310 | 7.96 | 5.054 | 13.01 | 668.6 | 100.0 |
| | June 25 | 37–45 | 40.63 | 2.95 | | .900 | 3.99 | 1.27 | 5.26 | .449 | .182 | 8.04 | 4.950 | 12.99 | 669.8 | 62.5 |
| | July 9 | 48–55 | 73.76 | 3.05 | | .710 | 4.87 | 1.73 | 6.60 | .217 | .092 | 8.32 | 6.946 | 15.26 | 554.6 | 81.5 |
| | July 23 | | | 3.33 | | .515 | 6.14 | 2.95 | 9.09 | .251 | .099 | 10.84 | 3.526 | 14.36 | 596.3 | |
| | Aug. 3 | (1) | | 3.36 | .0004365N | .512 | 5.76 | 4.16 | 9.92 | .198 | .079 | 11.64 | 3.253 | 14.89 | 571.6 | |

[1] Soft ripe.

TABLE 2.—*Changes in hydrion concentration, chemical composition, and weight of 5 varieties of apples in the earlier stages of development in 1929*

| Variety | Date | Average weight | Active acidity | | Titratable acidity | Sugars | | | Tannin | Solids | | | Water as percentage of total solids | Increment in weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | pH | CH | | Reducing | Sucrose | Total | | Soluble | Insoluble | Total | | |
| | | *Grams* | | | *Percent* | *Percent* | *Percent* | *Percent* | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Baldwin | Apr. 29 | 0.294 | 3.73 | 0.0001862N | 0.679 | 0.96 | 0.40 | 1.36 | 0.720 | 7.20 | 7.56 | 14.76 | 577.51 | |
| | May 11 | 3.84 | 3.12 | | 1.344 | 2.10 | .22 | 2.32 | .696 | 7.52 | 5.20 | 12.72 | 669.96 | 1,206.1 |
| | May 29 | 21.07 | 2.88 | .001318N | 1.572 | 2.45 | .57 | 3.02 | .404 | 5.96 | 4.82 | 10.78 | 827.64 | 448.7 |
| | June 10 | 35.3 | 2.96 | | 1.431 | 3.47 | .57 | 4.04 | .380 | 6.92 | 6.70 | 13.62 | 634.21 | 67.5 |
| | July 3 | 54.6 | 2.97 | | 1.021 | 3.76 | .53 | 4.29 | .284 | 6.36 | 7.94 | 14.30 | 599.30 | 54.6 |
| | Aug. 16 | 140.7 | 3.22 | | 1.055 | 7.16 | 1.23 | 8.39 | .206 | 10.32 | 7.60 | 17.92 | 458.04 | 157.6 |
| Grimes Golden | May 7 | 0.833 | 3.42 | .0003802N | .706 | 1.62 | .44 | 2.06 | .465 | 7.84 | 6.90 | 14.74 | 578.42 | |
| | May 28 | 10.5 | 2.99 | | 1.586 | 2.98 | .26 | 3.24 | .911 | 7.00 | 6.60 | 13.60 | 635.29 | 1,160.5 |
| | June 7 | 15.0 | 2.90 | .001259N | 1.492 | 3.78 | .88 | 4.66 | .526 | 7.88 | 7.88 | 15.76 | 534.52 | 42.8 |
| | June 28 | 46.4 | 3.06 | | 1.156 | 4.04 | .72 | 4.76 | .284 | 6.76 | 8.15 | 14.91 | 570.69 | 209.3 |
| | July 23 | 73.2 | 3.16 | | .894 | 6.20 | 1.88 | 8.08 | .216 | 9.36 | 8.34 | 17.70 | 464.97 | 57.7 |
| | Aug. 16 | 91.4 | 3.39 | | .755 | 7.46 | 2.01 | 9.47 | .193 | 10.93 | 6.94 | 17.87 | 459.60 | 24.8 |
| Launette | May 11 | 1.03 | 4.36 | .00004365N | .840 | 2.53 | .18 | 2.71 | 3.122 | 9.52 | 7.00 | 16.52 | 505.33 | |
| | May 29 | 6.94 | 3.69 | .0002042N | .874 | 3.18 | .12 | 3.30 | 2.425 | 7.96 | 7.84 | 15.80 | 532.91 | 573.7 |
| | June 10 | 13.16 | 3.79 | | .685 | 4.62 | 1.49 | 6.11 | 3.417 | 9.24 | 8.99 | 18.23 | 448.55 | 89.6 |
| | June 29 | 26.1 | 3.78 | | .659 | 4.63 | .48 | 5.11 | 1.925 | 7.60 | 8.82 | 16.42 | 509.01 | 98.3 |
| | July 23 | 43.66 | 4.08 | | .491 | 6.76 | .88 | 7.64 | 1.274 | 9.28 | 8.59 | 17.87 | 459.60 | 67.2 |
| | Aug. 16 | 63.5 | 4.23 | | .393 | 6.40 | 2.80 | 9.20 | .851 | 11.14 | 7.54 | 18.68 | 435.33 | 45.4 |
| Summer Rambo | Apr. 29 | 0.390 | 4.08 | .00008318N | .665 | .84 | .34 | 1.18 | .505 | 7.44 | 11.88 | 19.32 | 417.60 | |
| | May 7 | 2.56 | 3.24 | | 1.176 | 1.53 | .14 | 1.67 | .783 | 6.64 | 6.23 | 12.87 | 677.00 | 556.3 |
| | May 28 | 25.0 | 2.79 | .001622N | 1.666 | 3.08 | .25 | 3.33 | .592 | 6.44 | 7.21 | 13.65 | 632.60 | 876.5 |
| | June 7 | 29.5 | 2.80 | | 1.371 | 4.57 | .40 | 4.97 | .837 | 7.40 | 6.12 | 13.52 | 639.64 | 18.0 |
| | June 28 | 77.0 | 2.89 | | .840 | 5.66 | .44 | 6.10 | .301 | 7.48 | 5.53 | 13.01 | 668.64 | 161.0 |
| | July 23 | 134.10 | 3.15 | | .618 | 7.06 | 1.17 | 8.23 | .280 | 9.24 | 4.83 | 14.07 | 610.73 | 74.1 |
| Malus angustifolia | May 17 | 1.51 | 3.05 | .0008913N | 1.613 | .90 | .17 | 1.07 | 1.663 | 8.60 | 3.93 | 12.53 | 698.08 | |
| | June 4 | 6.00 | 2.78 | | 2.224 | .89 | .28 | 1.17 | .588 | 8.20 | 4.98 | 13.18 | 658.73 | 297.3 |
| | June 12 | 9.62 | 2.49 | .003236N | | | | | | | | | | 60.3 |

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Tables 1 and 2 show that in every series of samples of a variety, active acidity for the series is at a minimum in the initial sample, that is, in the youngest and smallest fruit. In several instances the sample taken on a given date was divided into two on the basis of size; in these cases the smaller fruits are lower in active acidity than the larger ones. Moreover, comparisons of the samples of a given variety obtained in the 2 years show that the active acidity of the smaller fruits is considerably below that of the larger ones.

There was in all cases a rather rapid change in hydrion-concentration values in the first few weeks of sampling. In 1928 this change had nearly or quite reached its maximum in the samples taken June 14, 4 weeks after sampling began. The amount of change during this period varied widely with variety, ranging from a threefold increase in active acidity in Baldwin through a ninefold increase in Rambo to a forty-fivefold increase in *Malus angustifolia*. The initial samples of Baldwin and Rambo in 1929 were somewhat smaller and had considerably lower active acidities, and the increases during the succeeding 4 weeks were larger, more than sevenfold in Baldwin and nearly twentyfold in Rambo.

Hooker (*22*) found active acidity values of pH 5.4 to 5.5 in bearing spurs of apple about the time of flowering, and the writer's determinations upon young fruits with petals attached have given values ranging from pH 5.1 to 5.4 for several varieties. The active acidity of the young ovary prior to the onset of rapid enlargement appears to approximate that of the vegetative parts upon which it is borne. That this is the case for other fruits as well will be shown in subsequent sections. By the time that fruits which have set and begun to enlarge can be distinguished from those which will drop, a considerable increase in active acidity has occurred.

The increase in active acidity is almost completed by the time the young fruits are 5 to 6 weeks old, when they have a diameter of 2 to 3 cm and a weight of 9 to 18 g, or from one twelfth to one eighth the volume and weight of mature specimens of the variety concerned. The hydrion concentration attained at the time the increase ceases varies widely with different varieties but appears to be fairly constant in successive years for a given variety. *Malus angustifolia* attains a maximum acidity three times as great as that of the Baldwin, Rambo, and Grimes Golden, which have maxima about six times as great as that of Launette. The varieties for which there are 3 years' records attained the following maximum values: Baldwin, pH 2.96, 2.89, and 2.88; Grimes Golden, pH 2.83, 2.87, and 2.90; Launette, pH 3.89, 3.72, and 3.69; Rambo, pH 2.97, 2.74, and 2.79, and *Malus angustifolia*, pH 2.52, 2.42, and 2.49.

After reaching these general levels, active acidity remains relatively stationary for a short period, then shows a sharp decline, which slows in rate as picking maturity approaches. *Malus angustifolia*, however, declines, then rises again. The general decline referred to has been observed in its later stages by Neller and Overley (*24*) and St. John and Morris (*34*). The length of the relatively stationary period varies with the date of maturity of the variety; in Williams and Rambo, which are commercially harvested in August and about mid-September, respectively, marked decline is apparent by July 23, whereas in the late-maturing varieties there is no very pronounced change until August or September.

The relation of the change in water content occurring in the young fruit to the concurrent change in active acidity is not immediately obvious from the usual statement of composition of the sample as made up of certain percentages of solids and of water together equaling 100 percent. It is made more obvious by recalculation of the data on moisture content, employing the total solids of the sample as a base and calculating the water present as percentage of the dry matter. This method of treatment has been applied to the data, and the results are stated in the next to the last column of tables 1 and 2. A like method has been employed with the data of subsequent tables.

In tables 1 and 2 there was in every case an abrupt increase in water content accompanying the rise in acidity and astringency, which can only mean that these increases in these constituents occur despite the opposed effect of dilution of the cell contents as a result of the rapid intake of water. The amount of the increase in water content varied widely among the varieties, and the percentage of water, calculated as percentage of the total solids, that is present at the time of maximum hydration is also somewhat variable. There was, however, a very definite relationship between the degree of active acidity attained at the peak of the upward rise and the water content of the fruit.

In the French apple Launette, the maximum active acidity attained in 1928 was pH 3.72, the sample containing 442 percent of water expressed as percentage of total solids. The rise of active acidity in this variety was from pH 4.79 to 3.72 (0.00001622N to 0.0001905N), and this rise was accompanied by an increase in water content from 400 to only 442 percent. In the other French crab apple, Amère du Surville, the maximum active acidity attained was pH 3.43 (0.0003715N), slightly less than twice that of Launette, but this higher level of active acidity is accompanied by a higher level of water content, namely, 594 percent. Five of the six remaining varieties attained maximum active acidities of the general order of pH 3.00 (0.001N), or about three times that of Amère du Surville, with an accompanying rise in water content to the general neighborhood of 700 percent. In the subsequent growth of the fruit the levels of water content reached at the stage under discussion drop somewhat. The water content of Launette fluctuates around 400 percent of the solids, that of Amère du Surville around 500 percent, and that of the other varieties around 600 percent for the remainder of the period of development, so that each variety rather early established and subsequently maintained a level of water content that was rather definitely related to the degree of active acidity existing in its tissues.

*Malus angustifolia* was unique in the course of its active acidity curve and also in its water relations. It reached a maximum water content of 708 percent on June 5, with a pH of 2.89 (0.001288N). Its active acidity continued to increase slowly throughout the season, reaching pH 2.42 (0.003802N) on October 3, but this increase was not accompanied by a further accumulation of water.

In 1929 the degree of hydration of the tissues present in the several varieties at the time maximum acidity was attained were in some cases higher, in others lower, than in 1928. As in 1928, Launette was materially lower in water content throughout the season than were the more highly acid varieties.

The degree of relationship existing between active acidity and percentage of water in the tissues is indicated by figure 1. The water in the tissues, calculated as percentage of total solids, has been plotted against the hydrion concentration for all the samples of tables 1 and 2 except those of *Malus angustifolia*. (This variety was omitted for the reason that the hydrion-concentration values lie entirely

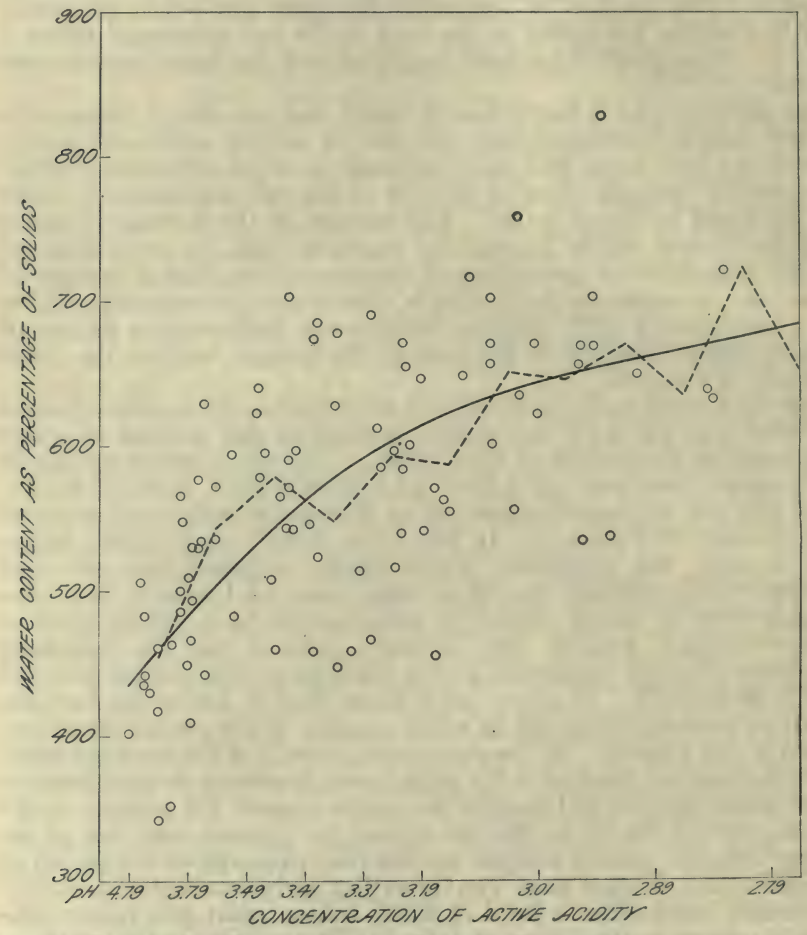


FIGURE 1.—Graph showing relationship between active acidity of expressed juice and water content of fruit, expressed as percentage of total solids, in apples during their development. Constructed from data of tables 1 and 2, omitting data for *Malus angustifolia*. The irregular line joins the group averages; the smooth line is a freehand curve averaging all the group averages.

beyond the range of those of the other varieties.) After the values for all the samples were plotted, they were averaged in groups to establish the line of group averages, and the resulting irregular line was then smoothed by a freehand curve. The slope of the curve indicates a rather high positive correlation between active acidity and percentage of water, regardless of variety or stage of development of the fruit. The slope of the curve flattens as maximum values for both active acidity and water content are reached, indicating a

lessened degree of correlation, and the scatter of the observed values about the line of regression also increases somewhat. This is exactly what would be anticipated, as it is in this region of maximum hydration that such factors as supply of water available to the plant, intensity of transpiration, and mechanical resistance to hydrational swelling offered by the anatomical structure of the fruit would exert largest effects upon the results. A considerable portion of the scatter of individual samples is attributable to varietal differences. Although the correlation is not perfect, the curve shows very conclusively that the water content of the fruit is a function of its active acidity.

The rate of percentage increase in weight of the fruit is greatest in the very young fruit and falls off rapidly with increase in age. This is apparent from the last column of tables 1 and 2, in which the increase in average weight per fruit for each interval between samplings is expressed as a percentage of the average weight per fruit at the beginning of the interval. As the intervals are not strictly uniform in length, a rigid comparison is not possible, but the data show that the percentage increase in weight is greatest in the smallest fruits sampled. Thus in 1929, sampling of Baldwin was begun when the fruits averaged 0.29 g in weight, and the increase in weight during the next 12 days was 1,206 percent, or over 100 percent per day. In the next interval the rate of increase in weight dropped to 24.9 percent per day, and in the third interval to about 6 percent. In Rambo the initial sample in the same year had an average weight per fruit of 0.39 g, the percentage increase in weight for an 8-day interval was 556.3 percent or 69.5 percent per day, in the next 21-day interval 876.5 percent or 41.7 percent per day, and in the third interval only about 2 percent per day. In the other varieties sampled in 1929 and in all the 1928 material the fruits were somewhat larger at initial sampling and the rates of increase in weight are somewhat lower, but in all cases there is a progressive decrease in the rate of increase in weight from the time sampling begins until the fruit is 5 or 6 weeks old and weighs 10 to 15 g. The period at which the fruit makes most rapid gains in total weight occurs later in the life history, when the fruit has attained one third to one half its mature weight. The distinction between percentage increase in weight and increase in total weight is shown in figures 2, 3, and 4, which include curves for both drawn from the same data.

The striking fact brought out by the graphs is the coincidence in time of the increase in active acidity, the increase in water content, and the period of most rapid percentage increase in weight. Whether these three changes begin simultaneously cannot be determined from the present data, as all three were already in progress in the youngest fruits examined, but in all cases they rise together from the first determination to the time at which maximum active acidity is reached, when water content ceases to increase, and percentage increase in the growth of the fruit abruptly slows to a fairly constant rate throughout the remainder of the period of development.

The relationship in time between changes in active acidity, water content, and rate of percentage increase in weight is presented graphically in figures 2, 3, and 4 for the 1928 series of Launette, Rambo, and *Malus angustifolia*. These varieties are representative of the apples studied in that the level of active acidity in Launette is exceptionally

low, that in Rambo is intermediate and typical of most dessert varieties, while that of *M. angustifolia* is remarkably high.[5]

In Launette (fig. 2) active acidity increased more than sixfold (0.00001622N to 0.0001023N) from May 18 to 29, with a further increase to 11 times its initial concentration (0.0001778N) by June 7. In the first interval the weight increment was 497.7 percent; in the second, 152.8 percent. Active acidity was stationary by June 14, but made a further advance to 0.0001905N on June 25. The weight increments for these two periods were 86.1 and 70.1 percent, respectively. With the beginning of decline in active acidity the curve of increment in weight progressively declined. Water content rose sharply, simultaneously with the initial rise in acidity, remained

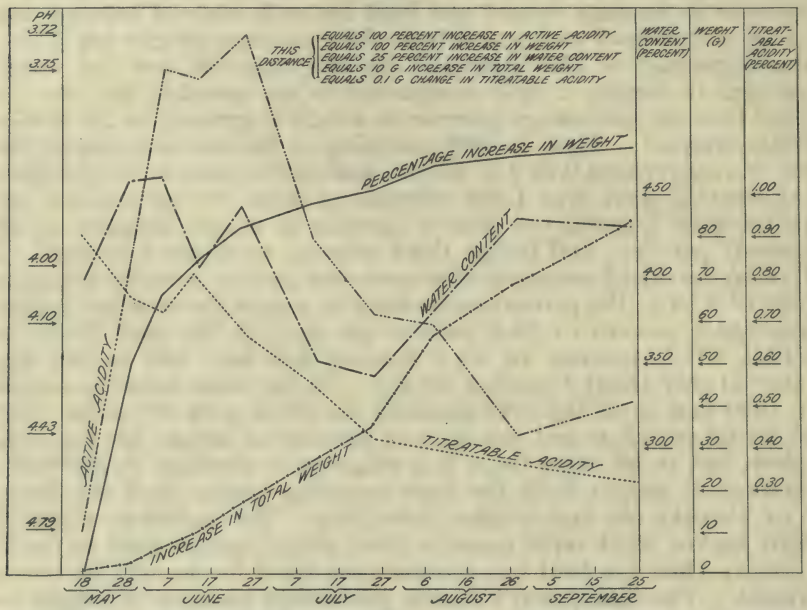


FIGURE 2.—Graph showing changes in active acidity, titratable acidity, water content, percentage increase in weight, and increase in total weight, in Launette, a French crab apple of the douce-amère group. The scales of the various curves are indicated on the graph.

stationary during the next interval, then declined and rose again in August and September. Titratable acidity was at the maximum in the first sample taken and declined somewhat irregularly throughout the season.

In Rambo (fig. 3) the increase in active acidity in 1928 was ninefold, from pH 3.70 to 2.74 (0.0001995N to 0.001822N). That the increase was already in progress when the fruit was first sampled is indicated by the fact that the active acidity of the initial sample of Rambo in

[5] Some difficulty was encountered in representing these changes by graphic methods, for the reason that they differ so enormously in magnitude. In the apples studied, the maximum active acidity attained was from 10 to 40 times the minimum concentration in the young fruit, while in the orange the maximum was over 1,300 times the minimum found. The increase in weight during the period of study ranged for the different fruits from about 10 times to more than 1,000 times the initial weight. The accompanying change in water content, expressed as a percentage of total solids, amounts at most to a doubling or tripling of the amount of water present per gram of solids. To represent these changes on the same scale is impossible. The important fact about them, however, is not their relative magnitude but their degree of coincidence in direction and in time. It therefore seemed permissible to plot them together against time, adopting for each a scale that would bring the curves within like limits and show the relation of the several processes in time. This has been done in the several graphs. The legends explain fully the scale employed in each case.

1928 had a value of pH 4.08 (0.00008318N) and rose to a maximum of pH 2.79 (0.001622N), or more than 19 times the initial concentration. Most of the active-acidity increase in 1928 occurred from May 23 to 31, and from May 31 to June 6. In the first interval the increment in weight was 566 percent; in the second, 83 percent. Water content of the tissues meanwhile rose from 530 to 722 percent of the dry matter, and titratable acidity increased from 0.94 to 1.43 percent. The curves representing active acidity, water content, titratable acidity, and increment in weight show a remarkable

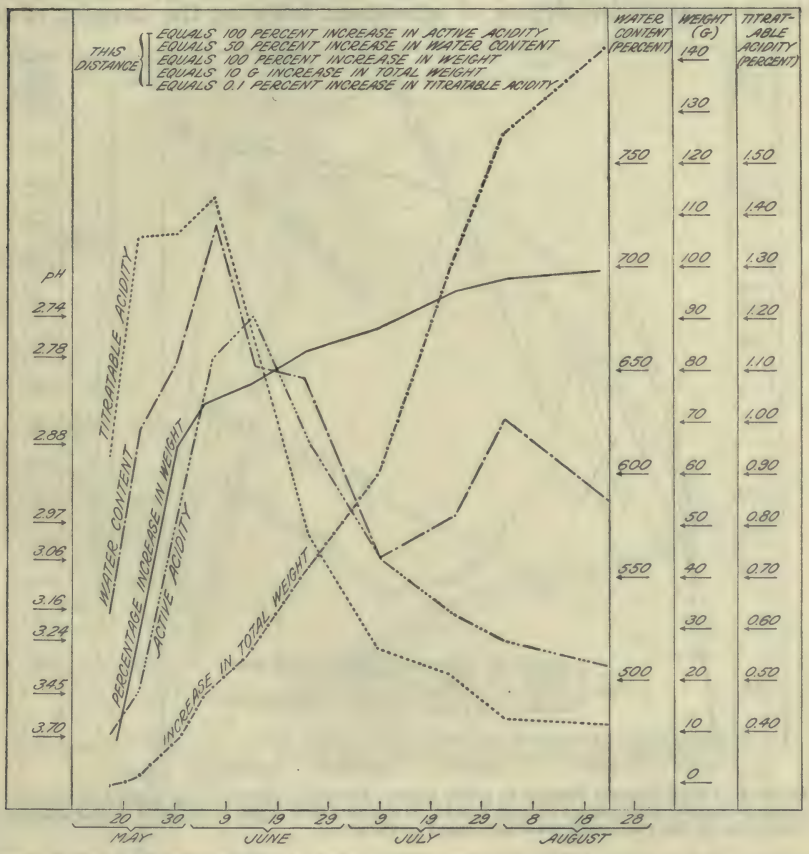


FIGURE. 3—Graph showing changes in active acidity, titratable acidity, water content, percentage increase in weight, and increase in total weight in Rambo, an early autumn dessert apple. The scales for the various curves are indicated on the graph.

parallelism in their ascending portions, the curve of increment in weight flattening sharply as the others begin to decline.

*Malus angustifolia* (fig. 4) differed from the dessert apples in that its active acidity, instead of rising rather rapidly to a maximum and then declining, continued to rise up to October 3, when it was more than 45 times the concentration found at initial sampling. The greater part of this increase occurred from May 15 to June 18 (0.00008318N to 0.002239N). This was also the period of the most rapid percentage increase in weight; the percentages being as follows: May 15 to 29, 419.7; May 29 to June 5, 114.6; June 5 to 18, 101.5,

followed by a drop to 22 percent for June 18 to 25. Water content rose rapidly from 444.3 percent of the dry matter on May 15 to 708.4 percent on June 5, after which it declined irregularly.

The degree of relationship in time between rate of rise in active acidity and rate of percentage increase in weight is shown in figure 5, which presents the data for changes in active acidity and percentage increase in weight for the Baldwin, Rambo, and Launette varieties in 1929 (table 2) in graphic form, plotted to the same scale. Not only did the period of the most rapid percentage increase in weight coincide with the period of increase in active acidity, but there was also a considerable degree of agreement between the amount of the

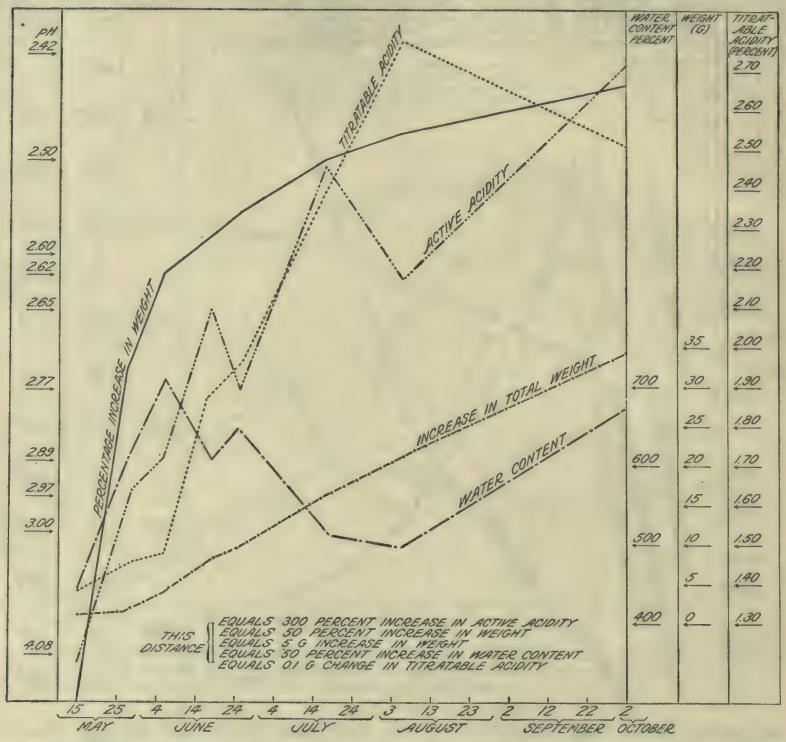


FIGURE 4.—Graph showing changes in active acidity, titratable acidity, water content, percentage increase in weight, and increase in total weight, in a native crab apple, a variety of *Malus angustifolia*. The scales for the various curves are indicated on the graph.

increase in active acidity and that of the concurrent percentage increase in weight. In Launette, active acidity increased more than fourfold in 18 days, with an accompanying weight increment of 573.7 percent. In Rambo, active acidity increased to 6.91 times the initial concentration in 8 days, with an accompanying weight increase of 556.3 percent; in the succeeding 21 days active acidity increased to 19.5 times the initial concentration, with an accompanying weight increase of 876 percent. In Baldwin, a fourfold increase in active acidity in 12 days was accompanied by an increase in weight of 1,206 percent; in the next 18 days a further increase in acidity to 7.1 times its initial amount was accompanied by a weight increase of 448.7 percent.

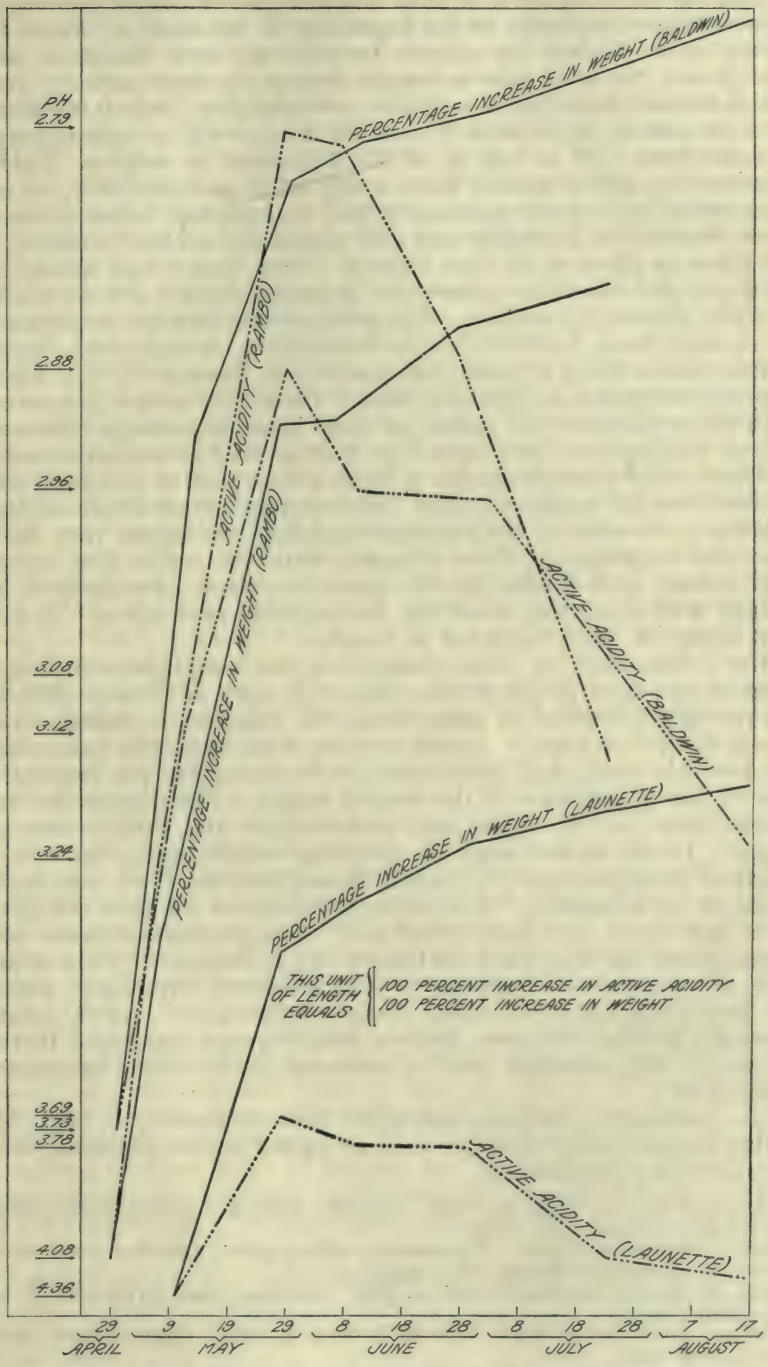


FIGURE 5.—Graph showing data for changes in active acidity and percentage increase in weight for Launette, Rambo, and Baldwin in 1929, plotted to a common scale.

The curves in figure 5 express the increase in weight per interval as percentage of weight at the beginning of the interval; hence they do not show directly the relation between the total change in active acidity and the total gain in weight during the same period. Launette increased more than fourfold in active acidity, from 0.00004365N to a maximum of 0.0002042N in 18 days, with an accompanying increase from 1.03 to 6.94 g, or 573.7 percent, in weight. Baldwin increased in active acidity from 0.0001862N to 0.001318N, or more than sevenfold, but the increase began very slightly below the maximum reached in Launette and the maximum acidity attained was 6.4 times as great as in that variety. The change was spread over 30 days, and the fruit meanwhile increased from 0.294 to 21.07 g, or 7,066 percent, in weight. Rambo increased in acid concentration in 30 days from 0.00008318N to 0.001622N, or 19½-fold, its final concentration being 8 times that reached in Launette. The accompanying increase in weight was from 0.390 to 25.0 g, or 6,310 percent.

In every instance the period of most rapid percentage increase in weight was that in which transition from a plane of low active acidity and low water content to one of high active acidity and high water content was in progress. The three changes everywhere occurred together. In some of the varieties sampling was begun very shortly after the initiation of these changes, with the result that most of their extent is indicated by the data; in others, the changes were already well under way when the first samples were taken. In every case, however, they coincided in time.

The relationship of these changes to the morphological development of the fruit is fairly clear from the work of Tetley (*36*), who has recently described in some detail the anatomical changes occurring in the young apple. At the request of the writer she has supplied considerable additional information as to the age of the fruit at the time of the appearance of the several stages. She divides the early development of the apple into meristematic and postmeristematic stages. In the former stage, as the name would imply, the cells are identical in appearance everywhere throughout the fruit, and nuclear divisions are abundant. This is the condition at the time the flowers open and for a few days afterward. The postmeristematic stage begins about the time the fruit has set and is indicated by the appearance of vacuolation in groups of cells scattered irregularly through the flesh while nuclear division continues elsewhere. As vacuolation proceeds, nuclear divisions become less frequent and rapid increase in size of cells presently sets in, resulting in the rapid enlargement of the fruit.

In a personal communication under date of January 3, 1931, Miss Tetley supplies the following data in regard to her material, which are quoted by permission:

Variety Wagener. May 26, 1927. Flowers opening. Diameter of apples 3 mm. End of meristematic stage.

June 2. Diameter 6 mm. Vacuolation taking place, together with nuclear divisions. Increase in size of cells beginning.

June 10. Rapid increase in size of cells beginning, also formation of large intercellular spaces.

Variety Court Pendu Plat. May 29 to June 9, 1927. Approximate date of meristematic stage.

June 6. Vacuolation of cells, together with nuclear division.

June 16. Marked vacuolation of cells, increase in cell-size noticeable.

June 16 to August 7. Large increase in size of cells and intercellular spaces.

It thus appears that in Wagener and Court Pendu Plat growing in the vicinity of Leeds, Yorkshire, England, the meristematic stage passes over into the stage of vacuolation within 6 to 10 days after blooming, and marked vacuolation and increase in size of cells are established 14 to 17 days after. The youngest fruits secured in the present work in 1929 did not exceed 10 to 12 days of age, whereas the 1928 samples ranged from 14 to 20 days. The material was therefore just entering upon the postmeristematic stage of vacuolation and increase in cell size. The fact that active acidity is minimum in the youngest and smallest samples obtained (Baldwin and Summer Rambo, 1929) and rises rather rapidly with increase in age makes it highly probable that vacuolation and rapid increase in cell size is the anatomical accompaniment of the onset of rapid increase in weight, in water content, and in active acidity.

Tables 1 and 2 show that the sugar content of the young apple remains low until the period of rapid increase in active acidity and water content has passed. It then begins a rather slow, irregular increase which continues until 4 to 5 weeks before the fruit reaches picking maturity, when accumulation of sugars materially increases in rate. The data indicate that in the apple three fairly well defined phases may be distinguished with respect to sugar: (1) An initial phase in which the sugar content remains low by reason of the fact that development of the structural framework of the fruit converts it into other forms as rapidly as it enters the fruit; (2) a succeeding phase, in which gradual accumulation occurs because transport into the fruit exceeds the demand for structural materials and the rate of starch formation; and (3) a final phase, in which an accelerated rate of transport into the fruit, together with some production of sugar from the insoluble solids, results in rapid accumulation. Throughout the life of the fruit respiration is a factor limiting the rate of accumulation of sugars; but too little is known of the respiratory rate of fruit attached to the tree, particularly of fruit in the earlier stages, to determine precisely the extent of this influence.

In the young fruit titratable acidity increases to a maximum which is usually attained before active acidity has reached its maximum. Almost immediately afterwards it begins to fall off at a rate which increases somewhat with the approach of picking maturity. In general, the titratable acidity of picking-ripe fruit is about one third that of fruit 4 to 5 weeks old. In the native crab species *Malus angustifolia*, however, titratable acidity increased throughout the entire season and showed only a very slight decrease in mid-October. It is unlike other varieties, also, in the fact that in October samples active acidity was practically unchanged or even increased.

The total-solids content of the fruit is high in the youngest sample taken and declines with increasing age, reaching the minimum at approximately the time at which the fruit attains maximum active and titratable acidity and maximum astringency; that is, about the fifth or sixth week of life. From this point total solids make rather slow and irregular but definite gains, which reach a maximum when the fruit is 10 to 13 weeks old (July 9 to 26 in the varieties here employed); afterward total solids decline somewhat with the approach of maturity.

Total astringency, which includes the total content of materials oxidizable by potassium permanganate at room temperature, follows a course paralleling the change in titratable acidity. From the initial sampling there is a rapid increase which reaches a maximum about the time titratable acidity becomes maximum in amount; there is then a progressive decrease which becomes more rapid as maturity approaches. The nature of the materials concerned in these changes is conjectural. Estimated in terms of the conventional factor for tannin, their amount is extremely large, amounting at the end of May to about 10 percent of the total solids in Paragon, Williams, and Grimes Golden, and to 20 and 25 percent, respectively, of those of Amère du Surville and Launette (table 1). The early stages of development of the orange and grapefruit and of the strawberry are characterized by a high content of permanganate-oxidizable material, but neither the relative nor the absolute amounts approach the enormous quantities present in the French cider apple Launette.

#### CITRUS FRUITS

Bartholomew, working with Eureka lemon (*4*) found that in 4 weeks (Sept. 10 to Oct. 10) the hydrion concentration for this fruit shifted from pH 4.46 to 2.91 (0.0000346N to 0.000123N) with an accompanying change of water content from 53.9 to 75.4 percent. In the succeeding 6 months there was a gradual increase of active acidity to pH 2.30 (0.005N) and of water content to 88.9 percent (*4*, *table 1*). It was considered desirable to repeat the work of Bartholomew on several varieties of orange and grapefruit, in order to determine whether an abrupt change in acidity and water content is a usual occurrence in these less-acid fruits of the citrus group.

Collections [6] of 3 varieties of orange and of 2 varieties of grapefruit were made at the fruit disease field station at Orlando, Fla., at approximately weekly intervals from June 7 to November 21, 1927. Immediately after being picked, the fruits were wrapped, packed in moistened paper, and forwarded by parcel post to the laboratory at Washington, D.C. All were received in good condition. Determinations of hydrion concentration and preservation of samples for analysis were made on the day of receipt, which was usually the third or fourth day from the date of picking.

Two series of samples were taken. The most complete of these consisted of fruits from the June bloom of an unnamed seedling orange and of a seedling grapefruit. At the time the first collection was made (July 15) the fruits of the orange ranged from 0.5 to 1.0 cm in diameter and averaged 0.20 g in weight. Those of the grapefruit were slightly larger and averaged 0.25 g in weight. Twelve collections were made, the last on November 21. The fruit was still immature at that date, but the removal of the workers and the temporary closing of the station made continuation of sampling impossible. The results are presented in table 3.

In addition to the June-bloom fruit, for which analyses are presented in table 3, collections of fruit from the first spring bloom (February bloom) of the same trees were made, beginning June 7 and continuing at intervals of about 3 weeks through November 21.

[6] Secured through the kindness of Frederick A. Wolf, formerly of the Office of Fruit Disease Investigations, Bureau of Plant Industry.

The first samples taken were consequently 12 to 14 weeks old, but were very much larger than June-bloom fruit of like age. The quantities of fruit received on June 7 and 22 were unfortunately so small that all the material was required for the hydrion-concentration determinations and no analyses could be made. The later collections were larger in amount and analytical samples were taken. No samples were collected after November 21, when fruit of the spring bloom of these varieties is moving to market in some quantity. The fruits comprising the last collection were yellowing but were still somewhat immature. Results of analyses showed a close similarity in all respects to those for the later stages of the June-bloom fruit, as will be seen from the data for the seedling orange and the seedling grapefruit presented in table 4. Apparently, at the time the earliest samples were taken, a period of fairly rapid change in active acidity was in progress in both fruits, which was practically ended before it was possible to obtain sufficient material for analysis.

TABLE 3.—*Changes in weight, hydrion concentration, and chemical composition of June-bloom oranges and grapefruit in 1927*

| Species | Date | Average diameter | Average weight | pH | | Titratable acidity | Sugars | | | Astringent substances | | | Solids | | | Water in pulp | Water as percentage of total solids | Increase or decrease in weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pulp | Whole fruit | | Reducing | Sucrose | Total | Total | Tannin | Non-tannin | Soluble | Insoluble | Total | | | |
| | | *Centimeters* | *Grams* | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Seedling orange | July 15 | 0.5–1 | 0.20 | ------- | 4.96 | 0.66 | | | | | | | | | | | | |
| | July 22 | .7–1.2 | .33 | ------- | 5.17 | .66 | 1.60 | 1.10 | 2.70 | 0.880 | 0.155 | 0.725 | 8.80 | 23.81 | 32.61 | 67.39 | 206.6 | 65.0 |
| | July 30 | 1.0–1.7 | 2.0 | ------- | 5.31 | .66 | 1.98 | .00 | 1.98 | .757 | .019 | .738 | 8.32 | 19.47 | 27.79 | 72.21 | 259.8 | 506.0 |
| | Aug. 3 | 1.9–2.5 | 4.5 | ------- | [1] 5.78 | .66 | 1.70 | .26 | 1.96 | 1.025 | .278 | .747 | 6.84 | 17.00 | 23.84 | 76.16 | 319.4 | 125.0 |
| | Aug. 10 | 1.9–2.7 | 6.9 | [2] 4.87 | 5.76 | .69 | 2.18 | .98 | 3.16 | 1.110 | .351 | .759 | 8.16 | 19.04 | 27.20 | 72.80 | 267.6 | 53.3 |
| | Aug. 12 | 2.1–3.3 | 10.0 | ------- | 5.33 | .76 | 2.50 | .64 | 3.14 | 1.042 | .052 | .990 | 8.24 | 17.54 | 25.78 | 74.22 | 287.9 | 44.9 |
| | Aug. 20 | 2.6–3.7 | 18.5 | ------- | 4.79 | 1.16 | 2.70 | .13 | 2.83 | .705 | .057 | .648 | 6.16 | 17.10 | 23.26 | 76.74 | 329.9 | 85.0 |
| | Sept. 2 | 2.3–3.9 | 26.2 | 3.60 | 3.99 | 1.16 | 2.12 | .46 | 2.58 | 1.084 | .138 | .946 | 7.44 | 12.95 | 20.39 | 79.61 | 390.4 | 41.6 |
| | Sept. 14 | 3.6–4.1 | 32.4 | 3.16 | 3.36 | 2.48 | 2.00 | .72 | 2.72 | .543 | .031 | .512 | 7.92 | 7.73 | 15.65 | 84.35 | 539.0 | 23.6 |
| | Oct. 1 | 4.0–4.5 | 67.9 | 2.66 | 2.91 | 2.72 | 1.53 | .78 | 2.31 | .492 | .077 | .415 | 7.84 | 5.75 | 13.59 | 86.41 | 635.8 | 109.5 |
| | Oct. 24 | 5.5–5.8 | 81.1 | 2.72 | [3] 2.75 | 2.98 | 2.44 | .96 | 3.40 | .443 | .043 | .400 | 8.68 | 4.79 | 13.47 | 86.53 | 642.5 | 19.4 |
| | Nov. 21 | 5.8–6.8 | 101.7 | [4] 2.67 | 2.83 | 2.27 | 2.98 | 2.76 | 5.74 | .398 | .027 | .371 | 8.96 | 3.98 | 12.94 | 87.06 | 672.8 | 25.4 |
| Seedling grapefruit | July 15 | .5–1.5 | .25 | ------- | 4.73 | | | | | | | | | | | | | |
| | July 22 | 1.0–1.5 | .43 | ------- | 5.53 | .73 | .50 | .30 | .80 | 1.040 | .195 | .845 | | | | | | 72.0 |
| | July 30 | 1.7–2.0 | ------- | ------- | 5.56 | 1.03 | 1.30 | .64 | 1.94 | 1.380 | .575 | .805 | 13.28 | 11.14 | 24.42 | 75.58 | 309.5 | ------- |
| | do | 2.5–2.6 | 5.01 | ------- | 5.47 | .74 | 1.15 | .33 | 1.48 | .770 | .068 | .702 | 13.12 | 9.99 | 23.11 | 76.89 | 332.6 | 1,065.0 |
| | Aug. 3 | 2.5–3.3 | ------- | ------- | 5.76 | 1.05 | 1.30 | .20 | 1.50 | 1.560 | .450 | 1.110 | 12.08 | 10.53 | 22.61 | 77.39 | 342.2 | ------- |
| | Aug. 10 | 3.4–3.8 | 24.6 | [5] 4.89 | [6] 5.74 | .77 | 1.42 | .76 | 2.18 | 1.160 | .355 | .805 | 11.28 | 13.81 | 25.09 | 74.91 | 298.5 | 391.0 |
| | Aug. 16 | 4.1–4.6 | 38.4 | ------- | 5.62 | .74 | 1.40 | .18 | 1.58 | .800 | .098 | .702 | 9.00 | 14.21 | 23.21 | 76.79 | 330.7 | 56.1 |
| | Aug. 24 | 4.5–5.5 | 60.0 | ------- | 5.05 | .52 | 1.25 | .52 | 1.77 | .647 | .055 | .592 | 7.60 | 11.99 | 19.59 | 80.41 | 410.4 | 56.2 |
| | Sept. 2 | 5.3–6.0 | 90.6 | 3.70 | 4.35 | .92 | 2.12 | 1.50 | 3.62 | .572 | .212 | .360 | 8.40 | 7.14 | 15.54 | 84.46 | 543.5 | 51.0 |
| | Sept. 14 | 5.9–6.8 | 90.2 | 3.60 | 4.23 | 1.50 | 2.66 | 1.68 | 4.34 | .399 | .039 | .360 | 8.04 | 5.81 | 13.85 | 86.15 | 622.0 | −.5 |
| | Oct. 1 | 7.8–9.4 | 240.6 | 3.53 | 4.31 | 1.75 | 2.59 | 2.71 | 5.30 | .444 | .054 | .390 | 9.08 | 4.37 | 13.45 | 86.55 | 643.5 | 166.7 |
| | Oct. 24 | 7.5–9.6 | 220 | 3.13 | 3.47 | 1.68 | 2.52 | 2.24 | 4.76 | .427 | .036 | .391 | 8.36 | 3.89 | 12.25 | 87.75 | 716.3 | −8.5 |
| | Nov. 21 | 9.0–9.5 | 244.7 | [7] 3.01 | [8] 3.27 | 1.76 | 2.96 | 3.38 | 6.34 | .380 | .007 | .373 | 9.52 | 3.88 | 13.40 | 86.60 | 646.2 | 11.2 |

[1] 0.000004898N.
[2] 0.00001349N.
[3] 0.001778N.
[4] 0.002138N.
[5] 0.00001288N.
[6] 0.000001738N.
[7] 0.000977N.
[8] 0.000537N.

TABLE 4.—*Changes in weight, hydrion concentration, and chemical composition of February-bloom oranges and grapefruit, from June 7 to Nov. 21, 1927*

| Species | Date | Average diameter | Average weight | pH | | Titratable acidity | Sugars | | | Astringent substances | | | Solids | | | Water in pulp | Water as percentage of total solids | Increase or decrease in weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Pulp | Whole fruit | | Reducing | Sucrose | Total | Total | Tannin | Non-tannin | Soluble | Insoluble | Total | | | |
| | | *Centimeter* | *Grams* | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Seedling orange | June 7 | 2.0–2.5 | 7.8 | ------- | [1] 3.48 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | do | 3.5 | 26.0 | ------- | 2.93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | 233.3 |
| | June 22 | 4.5–5 | 61.2 | ------- | [2] 2.80 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | 135.4 |
| | July 15 | 3.5–5 | 57.5 | ------- | 3.03 | 2.31 | 1.86 | 1.15 | 3.01 | 0.417 | 0.036 | 0.381 | 7.54 | 4.20 | 11.74 | 88.26 | 751.8 | −6.0 |
| | Aug. 10 | 4.5–5.5 | 65.7 | ------- | 3.06 | 1.66 | 2.74 | 1.23 | 3.97 | .488 | .062 | .426 | 8.60 | 5.60 | 14.20 | 85.80 | 604.2 | 14.2 |
| | Aug. 26 | 5.5–6.4 | 103.6 | [3] 2.92 | 3.15 | 1.61 | 2.64 | .61 | 3.25 | .455 | .032 | .423 | 7.36 | 6.72 | 14.08 | 85.92 | 610.2 | 57.6 |
| | Sept. 12 | 5.8 | 97.6 | [4] 2.70 | 3.16 | 2.04 | 2.64 | 1.60 | 4.24 | .420 | .042 | .378 | 7.88 | 4.78 | 12.66 | 87.34 | 689.8 | −5.8 |
| | Oct. 1 | 5.6 | 130 | 2.76 | ------- | 2.26 | 2.50 | 4.10 | 6.60 | .730 | .070 | .660 | 8.48 | 4.23 | 12.71 | 87.29 | 686.8 | 33.2 |
| | Oct. 24 | 5.8–6.5 | 122 | 3.07 | 3.16 | 1.58 | 3.44 | 2.79 | 6.23 | .431 | .075 | .356 | 9.04 | 2.84 | 11.88 | 88.12 | 741.7 | −6.1 |
| | Nov. 21 | 6.2–7 | 152.2 | [5] 3.22 | 3.35 | .96 | 5.40 | 4.54 | 9.94 | .358 | .016 | .342 | 11.20 | 2.42 | 13.62 | 86.38 | 634.2 | 24.7 |
| Seedling grapefruit | June 7 | 4.0–5.5 | 51.0 | [6] 3.93 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| | June 22 | 5.0–5.5 | 64.7 | 3.41 | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- | 26.8 |
| | July 12 | 7.0–8 | 164 | 3.44 | ------- | 1.50 | 1.75 | 1.65 | 3.40 | .514 | .026 | .488 | 8.20 | 4.96 | 13.16 | 86.84 | 659.8 | 153.4 |
| | Aug. 10 | 8.5–10.6 | 251.6 | 3.40 | ------- | 1.34 | 1.64 | 2.02 | 3.66 | .478 | .038 | .440 | 7.60 | 6.66 | 14.26 | 85.74 | 601.2 | 53.4 |
| | Aug. 26 | 10.2 | 433.3 | 3.43 | [7] 3.69 | 1.60 | 2.12 | 1.99 | 4.11 | .513 | .068 | .445 | 7.80 | 7.26 | 15.06 | 84.94 | 564.0 | 72.2 |
| | Sept. 13 | 8.8–9.7 | 305.2 | 3.17 | 3.38 | 1.53 | 2.79 | 2.30 | 5.09 | .424 | .044 | .380 | 8.40 | 3.66 | 12.06 | 87.94 | 729.1 | −29.5 |
| | Oct. 1 | 9.7–10 | 491 | [8] 3.11 | ------- | 1.31 | 2.78 | 3.92 | 6.70 | .710 | .070 | .640 | 9.04 | 2.42 | 11.46 | 88.54 | 772.6 | 60.8 |
| | Oct. 24 | 9.5–10.4 | 520 | 3.19 | [9] 3.35 | 1.67 | 4.10 | 2.18 | 6.28 | .370 | .034 | .336 | 9.48 | 2.92 | 12.40 | 87.60 | 706.4 | 5.9 |
| | Nov. 21 | 10.8–11 | 431 | 3.15 | 3.36 | 1.50 | 3.80 | 4.16 | 7.96 | .365 | .009 | .356 | 10.04 | 2.27 | 12.31 | 87.69 | 712.3 | −17.1 |

[1] 0.0003311N.
[2] 0.00138N.
[3] 0.001202N.
[4] 0.001995N.
[5] 0.0006026N.
[6] 0.0001175N.
[7] 0.0002042N.
[8] 0.0007762N.
[9] 0.0004467N.

Less complete series of samples of the February-bloom fruit of two varieties of orange, Homosassa and Parson Brown, and of Royal grapefruit were obtained. Sampling was begun on June 7 and continued to September 14, when it had to be discontinued. The results of the analyses of these partial series show for the period covered such close agreement with the series of table 4 that the data need not be presented. In the Parson Brown and Homosassa oranges the hydrion-concentration values for the pulp changed from 2.93 and 3.33 on June 7 to 2.73 and 2.88 on July 12, respectively, and afterward remained nearly stationary. In the Royal grapefruit the hydrion-concentration value of the pulp changed from 3.76 on June 7 to 3.23 on July 12 and reached 3.09 on August 26, remaining at the same value on September 14. In the Homosassa and Parson Brown oranges, as in the seedling orange, change in active acidity had largely been completed by the end of June, whereas in both the grapefruits it continued at a slower rate into August.

The preparation of the material for analysis presented some difficulties. In young fruit less than 2.5 to 3 cm in diameter, the segments of the pulp are so small and widely separated that a large quantity of fruit is required to yield sufficient pulp for analysis. As the quantity of available fruit was limited, it was necessary to make up the samples for analysis, without attempting to separate pulp from peel, by cutting slices through the center of a number of fruits. After September 2 the fruits had reached such size that the pulp could be separated from the peel, rag, and seeds, and the samples preserved for analysis on and after that date consisted of pulp only. Before September 2 the determinations of hydrion-concentration values were made upon juices obtained by grinding the entire fruit in a food chopper and expressing the juice with a tincture press. After that date determinations upon juices so obtained were supplemented by determinations upon juices from the pulp alone.

The determinations of hydrion concentration were made in duplicate with two Bailey hydrogen electrodes, and agreed within 0.05 pH. The juice of immature oranges contains substances which react with quinhydrone; consequently, quinhydrone could not be used for determining the hydrion concentration.

The data of table 3 on changes in active acidity of whole fruit and of pulp, in water content, in total weight, and in percentage increase in weight per interval for seedling orange and seedling grapefruit are represented graphically in figures 6 and 7, where they are plotted against time.

For both fruits there is a period, which extends up to August 12 for the orange and to August 16 for the grapefruit, in which the active acidity of the fruit at first decreases and then fluctuates irregularly at levels markedly below the initial values. Water contents also fluctuate, showing a small net gain. During this period the fruit makes very rapid gain in weight; the oranges increase from 0.20 g to 10 g, the grapefruit from 0.25 g to 38.4 g. This increase occurs almost wholly in the mesocarp, the segments of the pulp remaining very small and widely separated. When hydrion-concentration determinations upon the pulp were first attempted, on August 10 and 16, the pulps of individual fruits weighed less than 1 g each and it was difficult to secure sufficient juice for the determinations.

About mid-August rather abrupt changes in the relative volume of mesocarp and pulp set in. The pulp began to increase at a rate considerably greater than that of the accompanying increase in volume of the fruit, so that, as development proceeded, the mesocarp tissues were compressed into a progressively thinner and thinner enveloping layer. Hydrion concentration rose very rapidly in the orange and less rapidly in the grapefruit. From August 10 to October 1, the pulp of the orange increased 158-fold in active acidity (pH 4.87 to 2.66), subsequently changing very little. The acidity of the whole

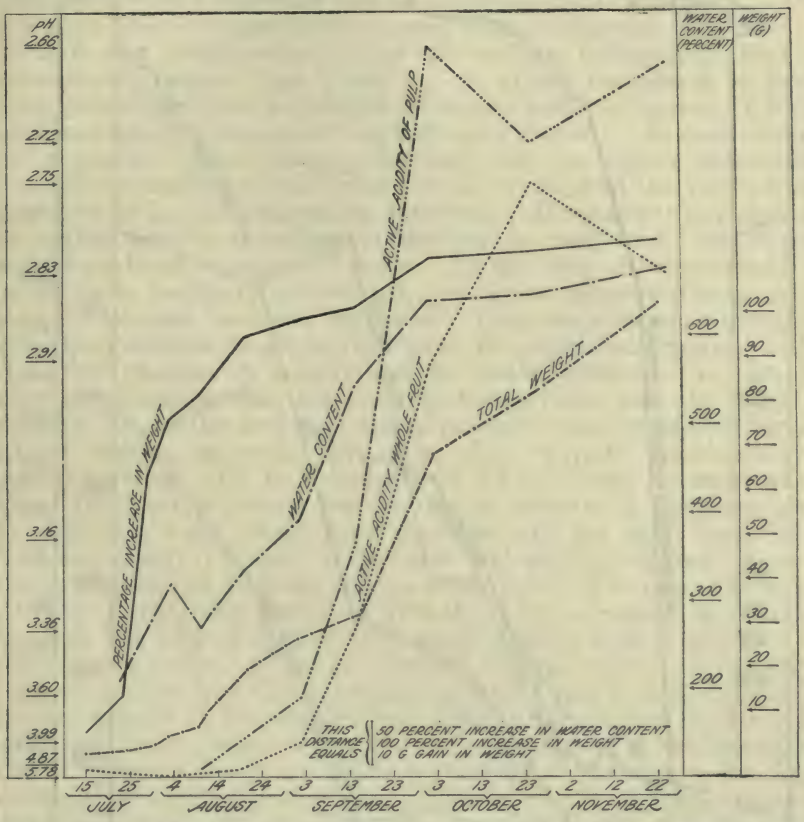


FIGURE 6.—Graph showing changes in active acidity, water content, total weight, and percentage increase in weight for seedling oranges, June bloom, from data of table 3. The scales of the various curves are indicated on the graph.

fruit increased less rapidly and continued to rise until October 23. The active acidity of the grapefruit increased more slowly and the rise was still in progress on November 21, at which time it had reached pH 3.27 for the whole fruit and pH 3.01 for the pulp. These values are equivalent, respectively, to 309 and 76 times the corresponding active-acidity concentrations found on August 10. At all stages the acidity of the pulp was higher than that of the whole fruit, and the amount of increase in acidity during any interval was considerably greater in the pulp. The fruit was still quite immature when circumstances compelled discontinuance of sampling on November 21. The fruit from

the February bloom was at that time market ripe. The hydrion-concentration data for the later samples of this fruit (table 4) show maximum acidity values of pH 2.70 for the orange (pulp) on September 12 and pH 3.11 for the grapefruit (pulp) on October 1; afterward there was a decrease in acidity, which was much more pronounced in the orange. This would indicate that the June-bloom fruit had nearly or

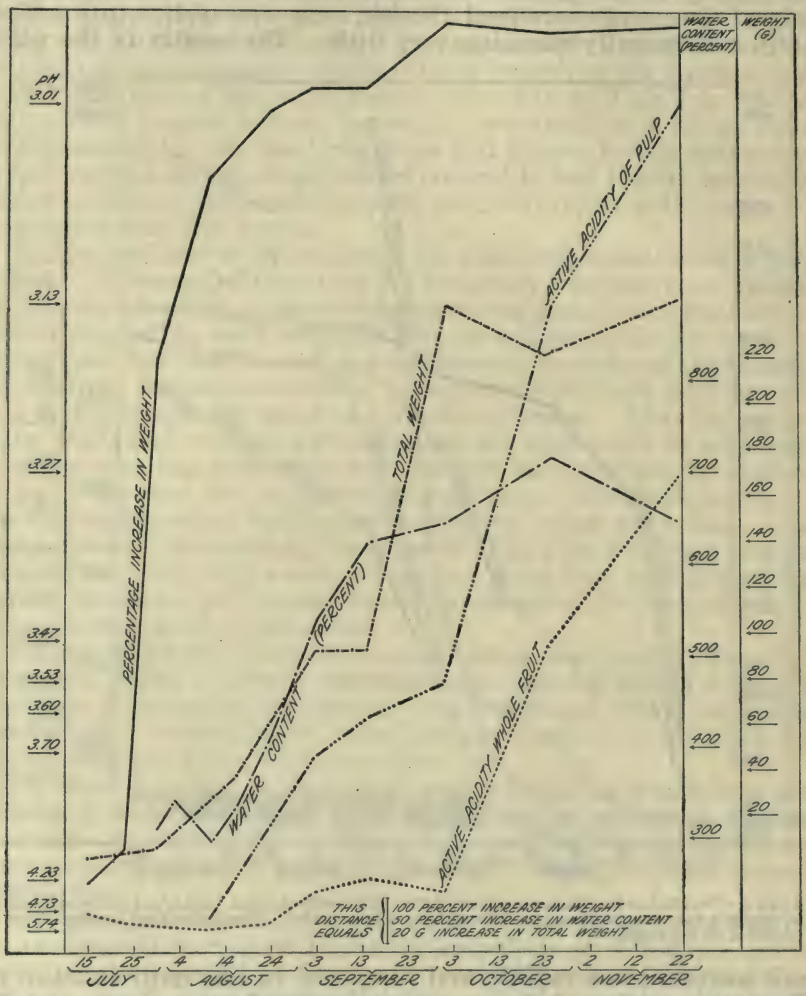


FIGURE 7.—Graph showing changes in active acidity, water content, total weight, and percentage increase in weight for seedling grapefruit, June bloom, from data of table 3. The scales for the various curves are indicated on the graph.

quite attained its maximum active acidity in the samples taken November 21.

The increase in active acidity in the June-bloom fruit was accompanied by a rapid rise in water content, which between August 10 and October 1 increased in the orange from 267 percent to 635 percent and in the grapefruit from 298 percent to 643 percent, calculated as percentage of dry matter. After October 1, water content fluctuated

within fairly narrow limits. Data for the February-bloom fruit (table 4) indicate that although the water content of the fruit fluctuated considerably in the last 3 or 4 months prior to picking, the general level maintained during this period was not greatly above that reached by the June-bloom fruit in October and November.

The graphs (figs. 6 and 7) show that the increase in active acidity and the increase in water content coincided in time. In the orange both began about August 10 and were completed about October 1; in the grapefruit both continued up to October 23, when water content began to drop off somewhat despite a continued rise in acidity. The crab apple (*Malus angustifolia*) showed similar behavior.

The earlier development of the citrus fruits differs from that of apples in one respect (figs. 6 and 7). In apples the period of maximum percentage gain in weight coincides with the period of most rapid increase in active acidity and in water content. In both orange and grapefruit (June bloom), however, the maximum percentage increase in weight occurred from July 22 to 30, and the rate fell off progressively in the succeeding intervals. Throughout this period the active acidity remained stationary or decreased, and water content made relatively small gains. By the time the rise in acidity and in water begins on August 10, the curves of percentage growth rate have become markedly flattened. They are somewhat irregular throughout their later course, but show no consistent relation to the concurrent changes in acidity and in water content. As already suggested, this difference between the citrus fruits and the apple is probably due to the fact that the citrus fruit consists of two highly distinct regions, mesocarp and juice sacs, or pulp, which do not develop together. Up to a diameter of 2.5 to 3.5 cm the increase in size of the fruit is almost wholly due to growth of the mesocarp; the glandular hairs which later develop into the pulp meanwhile remaining nearly constant in amount and making up only a very small percentage of the total volume of the fruit. The rate of increase in weight during this period of growth of the mesocarp is initially very high but falls off rapidly from week to week (figs. 6 and 7).

Increase in volume of the pulp begins simultaneously with the rise in active acidity and the large and sustained rise in water content. In every sample of June-bloom fruit taken after August 10, the pulp made up a larger proportion of the entire fruit than in the preceding sample. During the period from August 10 to October 1, the fruit was transformed from a structure consisting chiefly of mesocarp with a small percentage of pulp into one consisting chiefly of pulp. The rapid increase in volume of pulp was concurrent with the rapid increase in active acidity and in water content. This fact is suggested by the irregular form of the growth curve but is not clearly evident because of the inclusion in the total weight of the slower-growing mesocarp. Unfortunately, the full significance of the change in relative volume of mesocarp and pulp was not immediately recognized, so that determinations of weight of the two tissues separately throughout the series were not made. Such data if available would yield two curves, that for the mesocarp rising abruptly in July and flattening in August, and that for the pulp having its steepest portion in September.

The data of table 4 show a very decided decrease during October and November in the titratable acidity of the ripening orange, while

those of the grapefruit show little change. Collison (*8*) found much smaller decreases in titratable acidity in the several varieties of grapefruit which he studied than in various orange varieties examined over the same period, which extended from October 1 to the following May. Hawkins (*21*) found a slow decrease in titratable acidity in grapefruit picked at 4-week intervals from July 27 to November 1, followed by a slight increase in the December 1 samples. With respect to changes in both active and titratable acidity the grapefruit appears to stand in an intermediate position between the lemon, in which no appreciable decrease in either occurs with the oncoming of maturity (*4, 7*), and the orange, in which there is a marked decline in both as ripening proceeds.

The general results in the present study are in complete agreement with those of Bartholomew (*4*) and of Oppenheim and Winik (*25*) in showing that in both oranges and grapefruit there is a rather abrupt and large increase in both active and titratable acidity during the period of most rapid growth, accompanied by an abrupt rise in water content. This transition occupies only a few weeks, and it carries the fruit from the condition of high solids and low water content, with low active and titratable acidity, characteristic of the young fruit, to the condition of low solids and high water content, with high active and titratable acidity, characteristic of the full-grown fruit. Both before and after this period of rapid change there is a period in which all these changes occur at comparatively slow rates. It is only after the rapid changes have been completed that any appreciable accumulation of sugars or reduction of insoluble solids begins.

### CHERRIES

Five varieties of cherries, namely, Baumann May, Montmorency, Napoleon (Royal Ann), Nouvelle Royale, and St. Medard, were employed. Baumann May is an early sweet cherry of small size and mediocre quality, now passing out of cultivation; Nouvelle Royale is a late hybrid Duke, supposedly a cross of Early Richmond and May Duke; St. Medard is a black sweet variety of French origin that does not appear to have been introduced into cultivation in the United States; Napoleon is the most popular firm-fleshed sweet cherry; Montmorency, the most widely grown sour cherry. The varieties employed were chosen to represent early, late, sour, and sweet varieties insofar as the available material permitted.

The studies were begun in 1927 and continued for 3 years. Material for analysis was collected in each year, but no material of Napoleon or of Nouvelle Royale was available in 1929. The results of the analyses of the 1928 and 1929 series are presented in table 5.

TABLE 5.—*Changes in hydrion concentration and chemical composition of cherries throughout development*

| Series and variety | Date | Average diameter | Color or condition | Average weight | Active acidity | | Acidity of fresh juice | Sugars | | | Titratable acidity | Astringent substances | | Solids | | | Water as percentage of total solids | Increase in weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | pH | CH | | Reducing | Sucrose | Total | | Total | Non-tannin | Soluble | Insoluble | Total | | |
| 1928 series: | | *Mm* | | *Grams* | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Baumann May | May 5 | 6– 9 | | 0.176 | 4.79 | 0.00001622N | | 2.65 | 1.05 | 3.70 | 0.472 | 0.258 | 0.153 | 5.80 | 5.945 | 11.745 | 751.8 | |
| | May 15 | 8– 9.5 | | .577 | 4.20 | | 0.951 | 3.00 | .32 | 3.32 | .500 | .232 | .194 | 5.96 | 11.915 | 17.875 | 459.0 | 227.8 |
| | May 21 | 16–14 | White | 1.58 | 3.51 | .000309N | .938 | 4.81 | .55 | 5.36 | .750 | .138 | .082 | 8.04 | 2.194 | 10.234 | 877.5 | 173.8 |
| | do | 15–18 | Red | 2.22 | 3.54 | | .850 | 6.69 | .39 | 7.08 | .652 | .089 | .040 | 9.72 | 1.545 | 11.265 | 788.0 | 40.5 |
| | May 24 | 17–18.5 | Dark red | 2.63 | 3.53 | | .843 | 8.20 | .44 | 8.64 | .786 | .092 | .053 | 11.40 | 1,670 | 13.070 | 665.1 | 18.4 |
| | May 29 | | Soft ripe | 2.68 | 3.76 | .0001738N | .815 | | | | | | | | | | | 1.9 |
| apoleon | May 5 | 3.5–8 | | .121 | 4.74 | .0000182N | | .98 | 1.50 | 2.48 | .632 | .490 | .332 | 5.100 | 6.522 | 11.622 | 760.5 | |
| | May 15 | 10–12 | | .94 | 4.40 | | .629 | 2.64 | .20 | 2.84 | .417 | .458 | .358 | 5.320 | 6.425 | 11.745 | 751.8 | 676.8 |
| | May 21 | 10–14 | | 1.04 | 4.24 | | .717 | 1.77 | .39 | 2.16 | .530 | .446 | .273 | 4.640 | 9.724 | 14.364 | 596.3 | 10.6 |
| | May 28 | 12–15 | Whitening | 1.66 | 4.05 | | .817 | 2.46 | .46 | 2.92 | .622 | .358 | .268 | 4.920 | 10.101 | 15.021 | 565.7 | 59.6 |
| | June 5 | 16–18 | Red | 3.23 | 3.60 | | .918 | 5.15 | .52 | 5.67 | .752 | .207 | .135 | 7.720 | 1.845 | 9.565 | 940.0 | 94.5 |
| | June 22 | 19–20 | Ripe | 4.19 | 3.42 | | | 7.98 | .77 | 8.75 | .634 | .183 | .108 | 13.120 | 1.339 | 14.459 | 591.5 | 29.7 |
| | June 18 | | Canning ripe | | 3.38 | .0004169N | | | | | | | | | | | | |
| St. Medard | May 8 | 5–8 | | .480 | 4.52 | .0000302N | .884 | 2.70 | .62 | 3.32 | .664 | .482 | .244 | 6.080 | 6.362 | 12.442 | 703.8 | |
| | May 16 | 7–9 | | .780 | 4.16 | | .884 | 2.78 | .38 | 3.16 | .555 | .486 | .308 | 5.720 | 8.801 | 14.521 | 588.7 | 62.5 |
| | May 21 | 14–11 | | 1.06 | 3.77 | | 1.125 | 2.07 | .00 | 2.07 | .645 | .405 | .164 | 4.640 | 11.897 | 16.537 | 504.9 | 35.9 |
| | May 28 | 15–16 | White | 3.00 | 3.25 | | 1.206 | 6.08 | .13 | 6.21 | .975 | .222 | .073 | 8.120 | 2.814 | 10.934 | 814.9 | 183.0 |
| | May 28 | | Red | | 3.29 | | 1.261 | | | | | | | | | | | |
| | May 31 | 16–18 | | 3.44 | 3.28 | | 1.313 | 6.29 | 1.73 | 8.02 | 1.098 | .207 | .079 | 9.36 | 1.700 | 11.060 | 804.1 | 14.6 |
| | June 5 | 19–21 | | 4.17 | 3.19 | | 1.534 | 8.20 | .56 | 8.76 | 1.255 | .177 | .063 | 10.68 | 1.387 | 12.067 | 729.2 | 21.2 |
| | June 7 | 20–22 | Ripe | 4.49 | 3.18 | .0006607N | 1.782 | 9.29 | .57 | 9.86 | 1.295 | .215 | .089 | 12.48 | 1.216 | 13.696 | 630.0 | 7.6 |
| | June 9 | 20–22 | | | 3.36 | .0004365N | | | | | | | | | | | | |
| Montmorency | May 8 | 2–4 | | .231 | 4.74 | .0000182N | | | | | | | | | | | | |
| | May 16 | 6–8 | | .590 | 4.23 | | | | | | | | | | | | | 155.4 |
| | May 21 | 8–12 | | .635 | 4.11 | | .877 | 2.69 | .50 | 3.19 | .604 | .861 | .412 | 6.280 | 9.013 | 15.293 | 554.0 | 7.6 |
| | May 28 | | | .735 | 4.21 | | .964 | 1.49 | .24 | 1.73 | .682 | .701 | .320 | 4.960 | 13.366 | 18.326 | 445.8 | 15.7 |
| | June 5 | 10–14 | White | 1.22 | 3.56 | | 1.092 | 1.24 | .40 | 1.64 | .717 | .670 | .346 | 5.040 | 20.095 | 25.135 | 297.9 | 65.9 |
| | June 18 | | Full red | 3.51 | 2.91 | .00123N | 1.641 | 1.10 | .93 | 2.03 | 1.100 | .782 | .348 | 4.960 | 4.333 | 9.293 | 976.4 | 187.7 |
| | June 22 | | Canning ripe | 4.40 | 3.06 | .000871N | 1.990 | 8.62 | .84 | 9.46 | 1.645 | .438 | .187 | 15.32 | 1.375 | 16.695 | 499.1 | 25.3 |
| Nouvelle Royale | May 16 | 6–7 | | .82 | 4.31 | .00004898N | | 2.60 | .16 | 2.76 | .635 | .424 | .193 | 6.80 | 9.980 | 16.780 | 495.6 | |
| | May 28 | | | 1.35 | 4.08 | | 1.005 | 1.86 | 1.26 | 3.12 | .786 | .313 | .157 | 5.28 | 14.756 | 20.036 | 399.2 | 64.6 |
| | June 5 | 17–18 | | 3.84 | 3.34 | | 1.192 | 8.80 | .30 | 9.10 | .901 | .122 | .049 | 10.92 | 1.600 | 12.520 | 698.7 | 184.4 |
| | June 15 | | Ripe | 3.96 | 3.28 | .0005348N | 1.561 | 9.46 | .90 | 10.36 | 1.040 | .177 | .093 | 10.52 | 1.346 | 11.866 | 743.1 | 3.1 |

TABLE 5.—*Changes in hydrion concentration and chemical composition of cherries throughout development*—Continued

| Series and variety | Date | Average diameter | Color or condition | Average weight | Active acidity | | Acidity of fresh juice | Sugars | | | Titratable acidity | Astringent substances | | Solids | | | Water as percentage of total solids | Increase in weight |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | pH | CH | | Reducing | Sucrose | Total | | Total | Non-tannin | Soluble | Insoluble | Total | | |
| 1929 series: | | *Mm* | | *Grams* | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Baumann May | Apr. 27 | 6–10 | | | 4.30 | 0.00005012N | | 2.20 | 0.58 | 2.78 | 0.860 | 0.380 | | 5.84 | 11.073 | 16.913 | 491.26 | |
| | May 6 | | Greenish white | | 3.20 | .000631N | | 4.37 | | 4.38 | .874 | .276 | | 6.84 | 2.379 | 9.219 | 984.72 | |
| | do | | Reddened | | 3.42 | | | 6.24 | .16 | 6.40 | .800 | .231 | | 8.60 | 1.443 | 10.043 | 895.72 | |
| | May 10 | | Firm ripe | | 3.58 | | | 8.25 | .17 | 8.43 | .880 | .208 | | 10.76 | 1.465 | 12.225 | 717.99 | |
| | May 13 | | Full ripe | | 3.52 | | | 10.42 | .14 | 10.56 | .981 | .212 | | 13.92 | 1.035 | 14.955 | 568.67 | |
| Montmorency | Apr. 27 | 6–9 | | | 4.26 | .00005495N | | 2.13 | .04 | 2.17 | .833 | .968 | | 5.00 | 6.028 | 11.028 | 806.78 | |
| | May 6 | | | | 4.08 | | | 2.15 | | 2.15 | .961 | .743 | | 5.36 | 12.401 | 17.761 | 463.03 | |
| | May 14 | | | 0.83 | 4.08 | | | 1.28 | | 1.28 | .941 | .864 | | 5.44 | 18.251 | 23.691 | 322.10 | |
| | May 22 | | | .90 | 3.91 | | | .61 | .03 | .64 | .927 | .575 | | 3.64 | 15.364 | 19.004 | 426.21 | 8.4 |
| | May 27 | | Whitening | 1.25 | 3.35 | | | 1.76 | .04 | 1.80 | .954 | .346 | | 3.80 | 3.288 | 7.088 | 1,310.84 | 38.8 |
| | June 3 | | | 2.17 | 3.21 | | | 3.98 | .02 | 4.00 | 1.222 | .335 | | 6.52 | 1.886 | 8.406 | 1,089.62 | 73.6 |
| | June 7 | | Light red | 3.40 | 3.01 | .0009772N | | 7.13 | | 7.13 | 1.626 | .407 | | 10.92 | 1.286 | 12.206 | 719.27 | 56.6 |
| | June 11 | | Full ripe | | 3.10 | | | 8.12 | .18 | 8.30 | 1.740 | .393 | | 12.16 | 1.406 | 13.566 | 637.14 | |
| St. Medard | Apr. 27 | 9–10 | | | 4.10 | .00007943N | | 2.55 | .06 | 2.61 | 1.055 | 1.006 | | 6.00 | 5.900 | 11.900 | 740.34 | |
| | May 6 | 11–12 | | | 3.98 | | | 2.31 | .14 | 2.45 | .941 | .554 | | 5.08 | 12.048 | 17.128 | 483.84 | |
| | May 14 | | | | 3.36 | | | 3.89 | .08 | 3.97 | 1.183 | .416 | | 6.36 | 1.928 | 8.288 | 1,106.56 | |
| | May 17 | | Reddish white | | 3.32 | .0004786N | | 5.51 | .03 | 5.54 | 1.357 | .376 | | 8.16 | 1.418 | 9.578 | 944.06 | |

Insofar as possible, sampling was begun when the young fruits were 6 to 8 mm in length and from 4 to 6 mm in diameter and still retained the "husk." As the stones had not begun to harden, their separation from the flesh was tedious and difficult.

In cherries there is a progressive increase in active acidity from the youngest fruits obtainable up to those of full size. In the smallest fruits obtained the hydrion concentrations of the juices obtained were on the general level of those of aqueous extracts of the twigs, and differed very little with variety; in 1928 the value for the smallest fruits of Napoleon and Montmorency was 4.74, for Baumann May 4.79, and for Nouvelle Royale and St. Medard 4.31 and 4.52, respectively. There was a very rapid rise in active acidity with increase in size, attaining a maximum about the time the chlorophyll disappeared and the fruit began to redden, and decreasing somewhat as the fruit became fully ripe. The amount of the change differed with the variety. In Montmorency the change from pH 4.74 to 2.91 (0.0000182N to 0.00123N) represents a nearly seventyfold increase in active acidity; in Napoleon, Baumann May, and St. Medard active acidity showed an increase of twentyfold to twenty-threefold, and in the series of Nouvelle Royale, which is lacking in very early samples, the increase was more than tenfold. The time occupied by the change ranges from 40 days in Montmorency to 16 days in Baumann May, but in all cases the major portion of the change occurred in a shorter period, which was also the period of most rapid percentage increase in weight. Moreover, the change was in every instance practically completed before the beginning of the rapid increase in sugar content characteristic of the ripening period. In all cases there was a progressive increase in titratable acidity up to red ripeness, after which it usually declined somewhat as the fruit became overripe, as was likewise found to be the case by Hartman and Bullis (*20*).

The changes in active acidity, water content, and percentage increases in weight for Montmorency, a sour cherry, and St. Medard, one of the sweet varieties, are represented graphically in figure 8, the curves being drawn to the same scale. In both fruits the curve representing active acidity rises from the date of initial sampling until May 21 in Montmorency and May 28 in St. Medard, when it broke downward, then resumed its rise until red ripeness was reached. The curve representing percentage increase in weight has a similar break; in both varieties it rises sharply during the initial rise in acidity, then flattens somewhat as acidity ceases to rise, the rate of increase in weight varying with the fluctuations in rate of acidity increase. In both varieties water content decreases from initial sampling until the stone has hardened, then rapidly rises.

The increase in active acidity in the sour cherry Montmorency reaches a maximum nearly twice as high as that in the sweet variety St. Medard. It also undergoes greater decrease during ripening, so that the concentration in the ripe fruit is slightly less than twice that in St. Medard. The rise of water content in the St. Medard (to 814 percent) is less than that in Montmorency (to 976 percent), but its decline is also very much less, so that the water content at full ripeness is considerably higher in St. Medard than in Montmorency.

In all the varieties, as in Montmorency and St. Medard, there is a rapid hydration of the tissues accompanying the period of most rapid increase in acid concentration. This is also the period of most rapid

percentage increase in weight, chiefly due to intake of water. In the St. Medard, the most rapid increase in active acidity occurred between May 21 and 28. On May 21 the weight of the flesh was 1.06 g, of which 0.175 g was solids and 0.885 g was water. On May 28 the flesh weighed 3.00 g, of which 0.328 g was solids and 2.672 g water. While the solids increased 87 percent the water content increased 201 percent. In Montmorency the most rapid increase in acidity occurred between June 5 and 18. In this period the solids present per fruit increased only 6.5 percent (0.306 g to 0.326 g) while the water increased 248 percent (0.914 g to 3.184 g). A similar change occurred in the other varieties, resulting in a condition of maximum hydration of the fruit about the time chlorophyll disappeared and reddening had

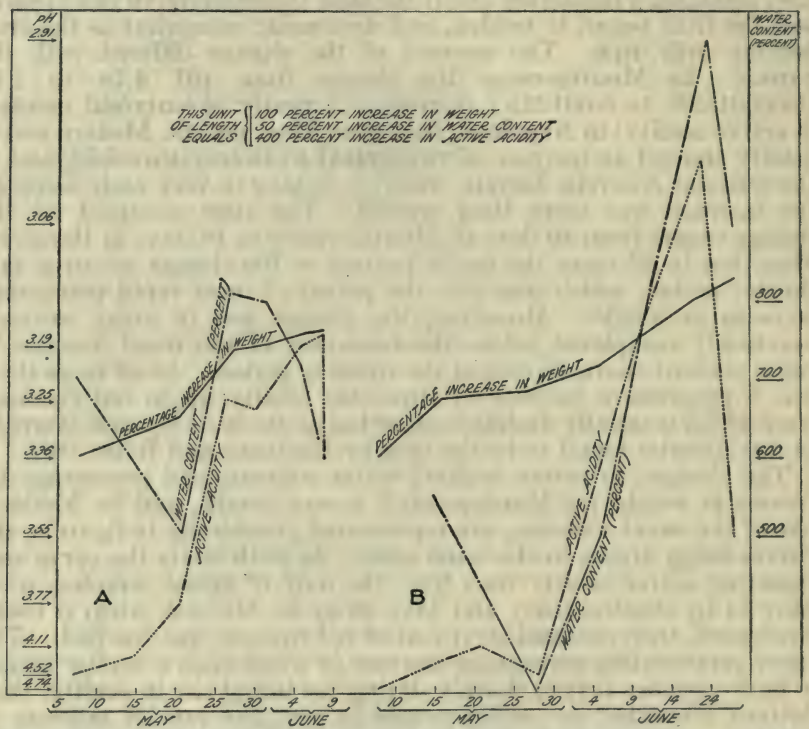


FIGURE 8.—Graph showing changes in active acidity, water content, and percentage increase in weight in St. Medard (*A*) and Montmorency (*B*) cherries during development and ripening, from data of table 5, plotted to common scale.

set in. As ripening proceeded there was a marked decline in water content as sugars accumulated in the fruit.

The course of the change in water and solids in the cherry differs somewhat from that in other fruits. In the very young fruits there is an initial stage of rather high moisture content, followed by a very abrupt decline. As the fruit whitens, water content again rises rapidly to a maximum, then declines as the fruit becomes fully ripe. The firm-fleshed varieties Napoleon and Montmorency attain a somewhat higher water content in the whitening period than do the other varieties studied, but return to the general level of the others by the time they are fully ripe.

At various periods collections of leaves and of fruiting spurs and twigs were made in order to secure some data on the range of hydrion concentration in the vegetative parts. As it was impossible to express any liquid from the pulp resulting from grinding leaves or twigs in a food chopper, the ground material was transferred to beakers, covered with a measured quantity of distilled water, macerated for 30 minutes, and pressed in a tincture press. By prolonged pressure it was possible to remove about 95 percent of the added water from the ground twigs, but only about 80 percent could be recovered from the excessively viscous leaf pulp. Hydrion determinations were made upon these aqueous extracts (table 6). A second extraction with water yielded values differing by only 0.01 to 0.04 pH from those obtained with the first extracts.

A few hydrion determinations made upon the expressed juice of the crushed seeds indicated that the active acidity of the very young embryo is low and that it rises to a maximum about the time the fruit becomes full grown and declines again at full ripeness, but the determinations were too few to be conclusive.

TABLE 6.—*Hydrion concentration of leaves, young wood, and seeds in cherries*

| Variety | Date | Part | pH |
|---|---|---|---|
| Napoleon | May 5, 1928 | Leaves, water extract | 4.74 |
| | do | Wood, 1-year twigs | 4.40 |
| St. Medard | May 8, 1928 | Leaves, water extract | 5.75 |
| | do | Wood, season's growth | 4.33 |
| | May 27, 1927 | 1-year stems | 4.80 |
| | Apr. 27, 1928 | Seeds of fruits 6–9 mm in diameter | 5.44 |
| Baumann May | May 5, 1928 | Leaves, water extract | 5.41 |
| | do | Wood, 1-year twigs | 4.51 |
| | May 6, 1929 | Seeds of slightly reddened fruits | 3.88 |
| | May 13, 1929 | Seeds of full-ripe fruits | 5.33 |
| Montmorency | May 27, 1928 | Seeds of whitening fruits, average weight 1.25 g | 4.57 |
| | June 7, 1928 | Seeds of full-ripe fruits | 5.20 |

## BERRIES

### STRAWBERRIES

The strawberry was chosen for study as a fruit having a very short developmental period, since it passes from the flowering stage to full ripeness in approximately 4 weeks.

A portion of the material collected for a comparative study of the biochemistry of development in the strawberry was utilized in the present work. Three commercial varieties, namely, Dunlap, Howard 17, and Progressive, were sampled in 1927. Four pickings at intervals of 5 to 8 days were made, beginning when the largest berries on the plants were 10 to 12 mm in diameter and continuing until the fruit was fully ripe. The berries were transferred to the laboratory immediately after being picked, and each picking was graded into two or more lots on the basis of size and apparent maturity; no determinations of volume or weight were made. A portion of each lot was preserved for chemical analysis; the remainder was ground and expressed for the hydrion determinations, which were made with the Bailey hydrogen electrode.

The results obtained in 1927 led to a repetition of the work in 1928. Studies were made on the same varieties as well as on a number of others, and sampling was begun at an earlier stage in the development of the fruit. Blooming began 6 to 10 days later in 1928, and at the first sampling on May 17 it was possible to collect berries not more than 4 to 8 mm in diameter and having the withered petals still adhering to them.

The analytical data for the 1927 series are assembled in table 7. The results for the 1928 series are so completely in agreement with those of the 1927 series that it seems unnecessary to present the analytical data in full. The results of the determinations of hydrion concentration, titratable acidity, and water content are assembled in table 8.

TABLE 7.—*Changes in hydrion concentration and chemical composition of 3 varieties of strawberries at various stages of development in 1927*

| Variety | Date | Diameter | Active acidity | | Titratable acidity | Sugars | | | Astringent substances | | | Solids | | | Water | Water as percentage of total solids | Stage of development |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | pH | CH | | Reducing | Sucrose | Total | Total | Tannin | Non-tannin | Soluble | Insoluble | Total | | | |
| | | *Mm* | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | |
| Dunlap | May 12 | 10–12 | 3.68 | 0.0002089N | 0.910 | 1.25 | 0.23 | 1.48 | 1.070 | 0.652 | 0.418 | 4.48 | 8.79 | 13.27 | 86.72 | 653.5 | Very hard green. |
| | May 20 | 10–12 | | | .983 | 1.13 | .39 | 1.52 | .740 | .476 | .264 | 4.08 | 8.15 | 12.23 | 87.76 | 717.5 | Do. |
| | do | 12–15 | 3.57 | | .942 | 1.41 | .35 | 1.76 | .510 | .300 | .210 | 4.04 | 7.28 | 11.32 | 88.67 | 783.3 | Dark green. |
| | do | 15–20 | | | 1.050 | 1.54 | .12 | 1.66 | .482 | .276 | .206 | 4.20 | 6.83 | 11.03 | 88.97 | 806.6 | Do. |
| | May 28 | 18–25 | 3.48 | | 1.082 | 1.92 | .37 | 2.29 | .378 | .230 | .148 | 4.56 | 4.92 | 9.48 | 90.52 | 954.7 | Whitening. |
| | do | 18–28 | 3.35 | | 1.030 | 2.28 | .30 | 2.58 | .274 | .148 | .126 | 4.76 | 3.93 | 8.69 | 91.31 | 1,050.7 | 25 percent pale red. |
| | do | 18–28 | 3.43 | | .942 | 3.22 | .46 | 3.68 | .290 | .210 | .080 | 5.72 | 3.69 | 9.41 | 90.59 | 962.7 | Fairly deep red. |
| | June 3 | 18–28 | 3.34 | .0004571N | .740 | 3.32 | 1.10 | 4.42 | .254 | .128 | .126 | 5.76 | 3.08 | 8.84 | 91.16 | 1,031.2 | Soft ripe. |
| Howard 17 | May 12 | 10–12 | 3.98 | .0001047N | .844 | 1.80 | .38 | 2.18 | 1.294 | .920 | .370 | 5.00 | 6.44 | 11.44 | 88.36 | 772.3 | Very hard. |
| | May 20 | 10–12 | 3.68 | | | | | | | | | | | | | | Do. |
| | do | 12–20 | 3.31 | | .840 | 1.92 | .51 | 2.43 | .620 | .390 | .230 | 4.64 | 5.34 | 9.98 | 90.02 | 902.0 | Hard green. |
| | do | 16–21 | 3.20 | | .864 | 2.40 | .50 | 2.90 | .480 | .304 | .176 | 5.00 | 4.66 | 9.66 | 90.34 | 935.2 | Whitening. |
| | May 28 | 25–30 | 3.35 | | .920 | 2.79 | .71 | 3.50 | .340 | .210 | .130 | 5.60 | 3.08 | 8.68 | 91.32 | 1,052.0 | 40 percent pale red. |
| | do | 25–30 | 3.39 | | .918 | 3.06 | .69 | 3.75 | .260 | .170 | .090 | 5.80 | 2.89 | 8.69 | 91.31 | 1,050.7 | 75 percent pale red. |
| | do | 25–30 | 3.18 | | .945 | 3.52 | .84 | 4.36 | .274 | .162 | .112 | 6.56 | 3.09 | 9.65 | 90.35 | 936.2 | Pale red. |
| | June 3 | 18–25 | 3.15 | | 1.050 | 3.66 | 1.20 | 4.86 | .350 | .180 | .170 | 6.44 | 3.25 | 9.69 | 90.31 | 931.9 | Do. |
| | do | 25–31 | 3.12 | .0007586N | .930 | 4.10 | 1.48 | 5.58 | .280 | .160 | .120 | 8.20 | 2.77 | 10.97 | 89.03 | 811.5 | Firm ripe. |
| | do | 25–31 | 3.36 | .0004365N | .726 | 4.08 | 1.30 | 5.38 | .262 | .152 | .110 | 7.04 | 2.80 | 9.84 | 90.16 | 916.2 | Full ripe. |
| Progressive | May 20 | 11–15 | 3.48 | .0003311N | .936 | 1.67 | .16 | 1.83 | .839 | .504 | .335 | 4.57 | 7.60 | 12.17 | 87.83 | 721.6 | Very green. |
| | do | 13–19 | 3.38 | | .994 | 1.90 | .45 | 2.35 | .562 | .322 | .240 | 4.56 | 6.55 | 11.11 | 88.89 | 800.0 | Dark green. |
| | May 28 | 12–25 | 3.23 | | 1.160 | 2.64 | 1.08 | 3.72 | .350 | .232 | .118 | 5.80 | 4.40 | 10.20 | 89.80 | 880.4 | Whitening. |
| | do | 15–21 | 3.12 | .0007586N | 1.050 | 2.81 | 1.04 | 3.85 | .274 | .164 | .110 | 5.84 | 3.83 | 9.67 | 90.33 | 934.1 | 60 percent red. |
| | June 3 | 15–22 | 3.19 | | 1.218 | 2.60 | 1.11 | 3.71 | .340 | .190 | .150 | 6.20 | 3.81 | 10.01 | 89.98 | 898.9 | 25 percent red. |
| | do | 15–22 | 3.22 | | .911 | 3.30 | 1.14 | 4.44 | .238 | .150 | .088 | 6.20 | 3.20 | 9.40 | 90.60 | 963.8 | Deep red. |
| | do | 18–27 | 3.27 | .000537N | .852 | 3.97 | 1.92 | 5.89 | .324 | .206 | .118 | 7.32 | 3.16 | 10.48 | 89.51 | 854.1 | Full ripe. |

TABLE 8.—*Hydrion concentration, titratable acidity, and water content of 5 varieties of strawberries at various stages of development and ripening in 1928*

| Variety | Date | Diameter | Stage of development | Active acidity | | Titratable acidity | Water as percentage of total solids |
|---|---|---|---|---|---|---|---|
| | | | | pH | CH | | |
| | | *Mm* | | | | *Percent* | *Percent* |
| Howard 17 | May 17 | 6–10 | | 4.37 | 0.00007079N | 0.681 | 533 |
| | do | 10–12 | | 3.95 | | .771 | 683 |
| | do | 12–15 | | 3.71 | | .879 | 609 |
| | May 29 | 18–30 | Nearly white | 3.23 | | | 894 |
| | do | 18–30 | Tinged red one side | 3.13 | .0007413N | .921 | 985 |
| | do | 18–30 | ⅓ surface red | 3.21 | | .906 | 977 |
| | do | 25–30 | All red | 3.14 | | | 945 |
| | June 11 | 25–30 | Firm red | 2.95 | .001122N | .924 | |
| | do | 25–32 | Full ripe | 3.06 | | .931 | 913 |
| Progressive | May 17 | 6–12 | | 4.24 | .00005754N | | 584 |
| | May 29 | 15–18 | | 3.31 | .0004898N | | 840 |
| | do | 21–25 | Nearly soft ripe | 3.37 | | | |
| | June 11 | 25–30 | Dead ripe and soft | 3.50 | | .763 | 695 |
| Chesapeake | May 17 | 4–6 | Petals still on | 5.10 | .00000794N | | |
| | do | 6–10 | | 4.47 | | | 452 |
| | May 29 | 7–12 | | 3.80 | | | |
| | do | 15–18 | | 3.55 | | | 708 |
| | June 11 | 25–28 | ⅓ to ½ red | 3.10 | .0007943N | 1.025 | 641 |
| | do | 25–28 | Ripe | 3.27 | | .984 | 754 |
| | June 20 | | Dead ripe and overripe | 3.51 | | .763 | 813 |
| New York | May 17 | 5–8 | | 4.31 | .00004898N | | 336 |
| | do | 8–12 | | 4.02 | | | 498 |
| | May 29 | 17–22 | | 3.39 | | | 758 |
| | do | 28–30 | Green | 3.24 | | | 787 |
| | do | 21–28 | ½ surface red | 3.22 | .0006026N | | |
| | June 11 | 18–27 | Light red | 3.22 | | 1.125 | |
| | do | 18–27 | Good ripe | 3.37 | | .897 | 753 |
| Portia | May 17 | 5–11 | | 4.04 | .0000912N | | 348 |
| | do | 11–17 | | 3.93 | | .809 | 546 |
| | May 29 | 12–15 | | 3.45 | | | 781 |
| | do | 18–28 | Whitening | 3.35 | | | 876 |
| | do | 25–30 | Half red | 3.32 | | | 1,072 |
| | June 11 | 18–26 | Light red | 3.21 | .0006166N | .938 | 974 |
| | do | 20–30 | Full ripe | 3.38 | | .844 | 974 |
| | June 20 | | Dead ripe | 3.34 | | .837 | 1,097 |

Table 7 shows that in all the varieties active acidity increases from the earliest stages to the attainment of full size and the beginning of development of color, then becomes more or less stationary, and decreases slightly as the fruit becomes fully ripe. There is a concurrent change in the same direction in titratable acidity and a very decided increase in the amount of water, made more apparent when water is expressed as percentage of total solids (table 7).

Table 8 shows the data on active acidity and water content at somewhat earlier stages in the development of the fruit. Both active acidity and water content were materially lower in the initial samples than in the preceding year. In all cases active acidity increased up to the point at which the fruit lost its chlorophyll and began to redden, remained fairly stationary as the fruit ripened, and decreased somewhat as the fruit became soft ripe. Water content increased somewhat irregularly up to a maximum which was reached as the fruit began to redden.

In the 1928 series of Chesapeake, in which the young fruits employed for the first sample had the petals still attached and for the most part unwithered, the extreme range of rise of acidity was from pH 5.10 to 3.10 (0.00000794N to 0.000794N) at half ripeness, a hundredfold increase. In Howard 17 the range of active acidity was from pH 4.37 to 2.95 (0.00007079N to 0.001122N), an increase of more than fifteen-

fold. It appears certain that determinations at equally early stages for the other varieties would have yielded similar results.

The relationship between the hydrion concentration and the percentage of water in the tissues of the strawberry is shown graphically

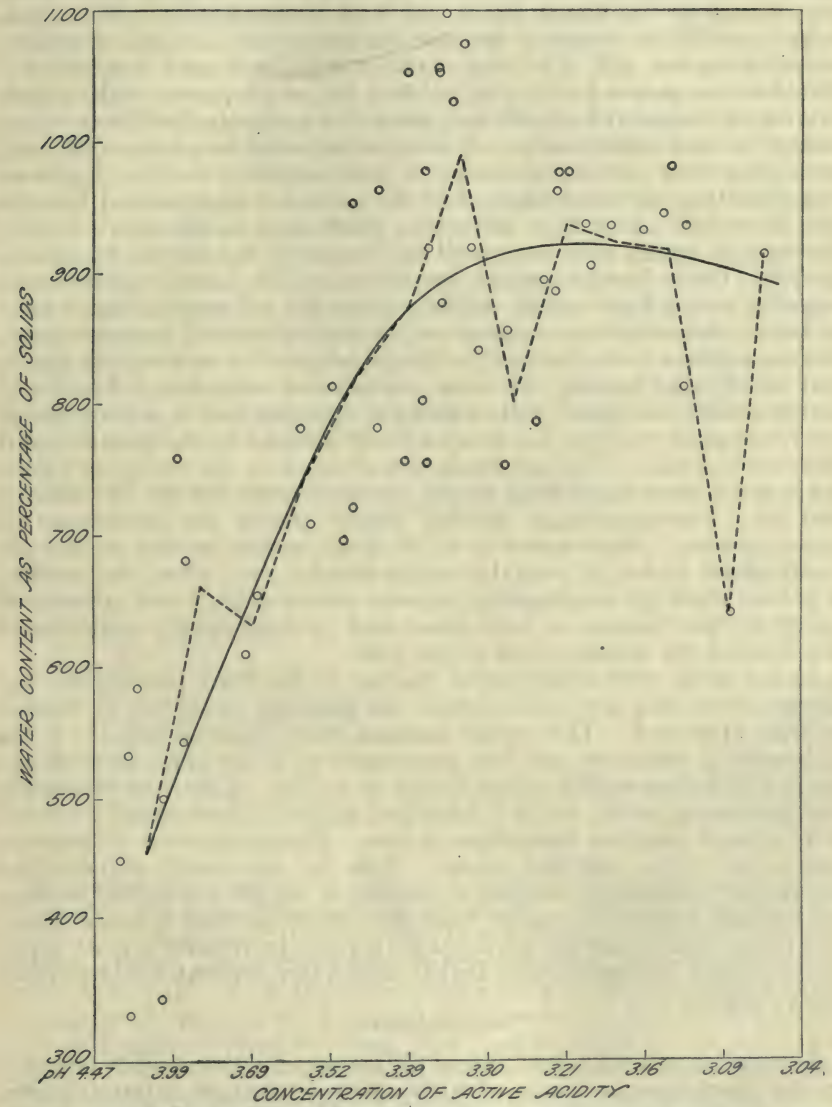


FIGURE 9.—Graph showing the degree of relationship between active acidity and percentage of water present in the tissues for strawberries. All data of tables 7 and 8 are included. The irregular line is the line of group averages; the curve is a smooth freehand curve.

in figure 9. In constructing the graph, all the data of tables 7 and 8 were used. These constitute determinations of hydrion concentration and water content for 51 samples, which comprise 8 series collected in 2 years and include 6 varieties of fruit taken at all stages of development from that at which some of the petals of the flower were still

adherent to that of full maturity. The values for water content were plotted against those for concentration of active acidity, and the group averages were determined and plotted as an irregular line on the graph. The curve, drawn freehand, indicates a very high degree of positive correlation of water content with active acidity at all concentrations of the latter below pH 3.24 (0.0005754N). From this point onward it becomes practically horizontal for active-acidity values between pH 3.24 and 3.06 (0.0005754N and 0.000871N). The downward trend of the right-hand end of the curve in the graph cannot be considered significant, since it was determined from a few values for one variety only. It may be regarded as a horizontal line, indicating that further increases in active acidity beyond hydrion-concentration values of about 3.24 do not result in increased absorption of water. A number of factors which may be operative in producing this result were suggested in discussing the curves for apples (p. 13). Other factors suggest themselves. The limit of imbibitional capacity of the hydrophilic colloids under the influence of acids may lie below the maximum value of active acidity reached in some varieties, as appears to be the case in the grapefruit, the native crab apple, and the Eureka lemon. In some varieties of strawberry the rise of active acidity continues well on into the ripening period, during which the hydrophilic colloids are progressively reduced in comparative and absolute amount. The accumulation of sugar in the course of ripening is much more rapid than at any previous period in the life history and to a correspondingly greater degree affects the percentage of water present. Since some or all of these factors, as well as the environmental factor of available water supply, may affect the results, it is clear that the relationship between active acidity and amount of water in the tissues is very close and is consistently maintained throughout the development of the fruit.

In the work with strawberries the age of the fruit making up any given sample was not known, since the blossoms could not be tagged as they appeared. The earlier samples were consequently made up of berries of unknown age but apparently at a like stage in development and falling within stated limits as to size. Later, as whitening and reddening set in, fruits in identical stages as determined by color were placed together regardless of size. Determinations of average weight per fruit were not made. Data for accurately determining the rate of percentage increase in volume or weight in relation to time are lacking, but it is apparent from the rate of increase in mean diameter of the fruits that the percentage increase in volume is most rapid in the period in which active acidity and water content are increasing most rapidly.

### BLACKBERRIES

In order to gain a general idea of the course of active-acidity changes in the blackberry, a series of hydrion-concentration determinations upon the Snyder variety was begun on May 26, 1927 (table 9); at that time most of the petals were still adherent and the fruits were not more than 1 to 1.5 mm in diameter. It was somewhat difficult to express sufficient liquid to permit of determinations with both Bailey and quinhydrone electrodes. It was found that the values obtained were unaltered when the determinations were repeated after the juice had been diluted with an equal volume of distilled water. Readings of pH 4.79 (0.00001622N) (Bailey) and pH 4.76 (quin-

hydrone electrode) were obtained on May 26. On May 31 readings of pH 4.81 (Bailey) and 4.79 (quinhydrone) were obtained upon fruits at a like stage, while older berries, 3 to 4 mm in diameter, gave a value of pH 4.45 with both electrodes. Later determinations showed a rapid increase in active acidity until the fruits were practically full grown and greenish white, showing no trace of red. At this stage the value for active acidity was pH 2.46 (0.003467N). As the fruit ripened the active acidity decreased to pH 3.06 in very soft ripe fruit. The change from pH 4.06 to 2.46, representing a more than thirty-ninefold increase of active acidity, occurred between June 6 and June 30; during this time the fruits increased from sixfold to twelvefold in volume. Determinations of active acidity upon the expressed juices of young shoots and leaves on May 26 and on July 25 gave values of pH 4.98 and 4.86, respectively, indicating that the active acidity of these parts remains rather constant throughout the period of development of the fruit. Moreover, these results indicate that the very young fruit begins its existence with an active acidity very closely approximating that of the vegetative parts, and progressively departs from this value as growth proceeds. The maximum acid concentration found in greenish-white berries on June 30 (pH 2.46, or 0.003467N) is more than 213 times that in berries with petals still attached on May 26 (pH 4.79, or 0.00001622N).

TABLE 9.—*Hydrion concentration of Snyder blackberry at various stages of development in 1927*

| Date | Part | pH | CH |
|---|---|---|---|
| May 26 | Twigs and leaves | 4.98 | 0.00001047N |
| 26 | Berries, petals just falling | 4.79 | .00001622N |
| 31 | do | 4.81 | |
| 31 | Berries, 3–4 mm in diameter | 4.45 | |
| June 6 | Berries, 5–8 mm in diameter | 4.06 | .00008710N |
| 22 | Berries, 12–15 mm, greenish white | 2.70 | .001995N |
| 30 | Berries, 15–18 mm, greenish white | 2.46 | .003467N |
| July 18 | Berries, full grown, chlorophyll out, no red | 2.56 | .002754N |
| 18 | Berries, hard red, no black | 2.58 | |
| 18 | Berries, firm ripe | 2.78 | .001660N |
| 18 | Berries, soft ripe | 2.91 | |
| 25 | Berries, full ripe, very soft | 3.06 | .0008710N |
| 25 | Leaves and petioles | 4.86 | .00001380N |

The series was repeated in 1928, and samples were taken for analysis. The analytical data are presented in table 10. The initial sample was about equal in age and size of berries to the second sample of 1927, and had an almost identical hydrion-concentration value—4.50 as compared with 4.45. As in the first series, active acidity rose rapidly to a maximum at the time the fruit had become distinctly red but was still firm and without blackish tinge, and then declined as the fruit reddened. The maximum acid concentration reached was 55 times that of the youngest samples taken. Water content rose abruptly as the fruit reddened, and subsequently declined as sugar began to accumulate in the fruit.

TABLE 10.—*Changes in hydrion concentration, water content, and chemical composition of Snyder blackberry and a wild dewberry throughout development*

| Variety | Date | Diameter | Stage of development | Active acidity | | Sugars | | | Solids | | | Water as percentage of solids |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | pH | $C_H$ | Reducing | Sucrose | Total | Soluble | Insoluble | Total | |
| | | *Mm* | | | | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* | *Percent* |
| Snyder blackberry | May 31 | 3–4 | | 4.50 | 0.00003162N | 1.64 | 0.85 | 2.49 | 6.49 | 9.72 | 16.21 | 505.0 |
| | June 8 | 4–9 | | 4.12 | | 1.37 | 1.08 | 2.45 | 6.20 | 17.17 | 23.37 | 328.0 |
| | June 18 | 12–14 | | 3.67 | | .26 | 1.16 | 1.42 | 2.44 | 9.67 | 12.11 | 725.0 |
| | July 2 | 17–20 | Faint red | 2.76 | .001738N | .34 | .76 | 1.10 | 2.92 | 9.66 | 12.52 | 698.7 |
| | July 16 | | Ripe | 2.86 | | 4.24 | .87 | 5.11 | 8.20 | 6.38 | 14.58 | 586.0 |
| Wild dewberry | June 5 | | Inflorescence and leaves | 4.91 | .0000123N | | | | | | | |
| | June 5 | 3–6 | | 4.77 | .00001698N | 1.38 | .0 | 1.38 | 5.72 | 11.03 | 16.75 | 497.0 |
| | June 19 | 5–7 | | 3.58 | | .82 | .74 | 1.56 | 2.92 | 13.95 | 16.87 | 492.8 |
| | June 27 | | Whitening | 3.12 | | .88 | .64 | 1.52 | 5.96 | 15.08 | 21.04 | 375.3 |
| | July 5 | | Underripe | 2.87 | .001349N | 5.10 | 1.60 | 6.70 | 5.28 | 6.67 | 11.95 | 736.8 |
| | July 13 | | Full ripe | 3.22 | .0006026N | 6.24 | 1.48 | 7.72 | 9.96 | 4.88 | 14.84 | 573.8 |

### DEWBERRIES AND RASPBERRIES

Concurrently with the work upon blackberries, determinations were made in 1927 upon Cuthbert, Latham, and Ranere raspberries, an unnamed purple raspberry, a wild dewberry, and a wild black raspberry. The limited amount of material of Latham and Ranere raspberries precluded the making of close series and the taking of samples for analysis, but such samples were taken in the case of the others, and the work was repeated in 1928. The results from the 1928 series of the dewberry are presented in table 10. The results with the various raspberries are so nearly identical in general character with those for the blackberry and dewberry that presentation of the data is deemed unnecessary. In all varieties the active acidity was low in the youngest sample taken, rose rapidly during the period of most rapid increase in size to a maximum attained as chlorophyll disappeared and the development of pigmentation began, and decreased as ripening proceeded. In the dewberry the increase was approximately eightyfold; in the various raspberries it ranged between fifteenfold and fiftyfold. In all varieties there was a very marked increase in water content with the attainment of maximum acidity, followed by decrease as ripeness was reached.

### ELDERBERRIES

Collections of elderberries (*Sambucus canadensis* L.), in 1927 were accompanied by collections of leaves and petioles, shoots of the current season's growth, and 1-year-old stems. The hydrion-concentration values for these vegetative parts were practically identical at the three tests (table 11). The largest berries obtainable on July 1 and 7 were 3 to 4 mm in diameter; on July 16 many of the berries were 6 to 7 mm in diameter—a sevenfold to tenfold increase in volume—and showed all stages of coloration from bright green through greenish red to dark red. A marked change in active acidity had occurred in the interval, the increase being twelvefold in the greenish fruits to more than twentyfold in the greenish-red fruits. On August 2, faintly reddened berries showed an active acidity more than 31 times as great as that of the sample taken July 7. Determinations of moisture content were not made.

TABLE 11.—*Hydrion concentration of elderberry at various stages of development in 1927*

| Date | Part | pH | CH |
|---|---|---|---|
| July 1 | Leaves and petioles | 5.36 | 0.000004365N |
| 1 | Young stems, season's growth | 5.41 | .00000389N |
| 1 | Berries, 3–4 mm in diameter | 4.89 | .00001288N |
| 7 | Berries, 4 mm in diameter | 4.96 | |
| 16 | Berries, 5½–6 mm in diameter | 4.05 | .00008913N |
| 16 | Berries, full grown, 6–7 mm but green | 3.87 | |
| 16 | Berries, greenish red, half ripe | 3.62 | .0002399N |
| 16 | Berries, dark red, firm | 3.73 | |
| 16 | Leaves and petioles | 5.46 | .000003467N |
| 16 | Young stems, season's growth | 5.49 | .000003246N |
| 16 | Woody 1-year stems | 5.47 | |
| Aug. 2 | Berries, full grown, faintly reddened | 3.44 | .0003631N |
| 2 | Berries, dark red | 3.75 | |
| 2 | Berries dark red, after 48 hours in laboratory | 3.84 | |
| 2 | Berries, deep black | 3.93 | .0001175N |
| 2 | Berries, black, soft, and shriveling | 4.04 | |
| 2 | Leaves and petioles | 5.50 | |

Partial repetition of the series in 1928, with especial attention to securing younger fruits, resulted in samples in which the petals were mostly unwithered and the ovaries were about 2 mm in diameter. In these fruits the hydrion concentration was 5.36 (0.000004365N), practically the same as that of the leaves and young stems. Faintly reddened berries had a hydrion concentration of 3.41 (0.0003981N); fully ripe berries, a hydrion concentration of 3.77. The change in active acidity in the course of development of the fruit is consequently somewhat greater than is indicated by the results of table 11, the active acidity of the faintly red berries being 90 times as great as that of the young fruits with petals attached.

### POKEBERRIES

Hydrion-concentration determinations were made July 19, 1927, upon the following parts of the pokeberry (*Phytolacca americana* L.): Leaves, terminal portions of shoots, racemes in which flowers were just opening, and berries 0.5 to 2 mm in diameter from which the petals had not yet wholly fallen away. These determinations yielded closely accordant values ranging from pH 5.49 to 5.57. The basal portions of stalks were more acid (pH 4.91). There was very little change in hydrion concentration until the fruit had become practically full-grown and somewhat reddened, when the active acidity began to rise, attaining its maximum as the fruit became full soft ripe. The hydrion-concentration values obtained for fruits of corresponding stages on September 26 and October 20 are not identical, but they agree in showing that active acidity doubled or tripled concurrently with the filling of the originally thin film of pulp with water, which accompanies ripening. The results are shown in table 12.

TABLE 12.—*Hydrion concentration in pokeberry at various stages of development*

| Date | Part | pH | CH |
|---|---|---|---|
| July 19 | Leaves | 5.55 | 0.000002818N |
| 19 | Stalks, terminal 12–18 inches | 5.49 | .000003236N |
| 19 | Stalks, basal halves | 4.91 | |
| 19 | Racemes, some flowers open, others just opening | 5.49 | .000003236N |
| 19 | Berries, 0.5–2 mm, petals not fallen | 5.57 | .000002692N |
| 19 | Berries, 5–6 mm in diameter | 5.65 | |
| Aug. 3 | Berries, 8 mm in diameter, green | 5.83 | |
| Sept. 26 | Berries, 8 mm, green | 5.46 | |
| 26 | Berries, full grown, slightly reddened | 5.19 | .000006457N |
| 26 | Berries, black but firm | 5.29 | |
| 26 | Berries, black, soft ripe | 5.16 | .000006918N |
| Oct. 20 | Racemes, petals beginning to fall | 5.62 | |
| 20 | Berries, 1–3 mm in diameter | 5.67 | .000002138N |
| 20 | Berries, 3–5 mm in diameter | 5.55 | |
| 20 | Berries, full grown, green | 5.55 | |
| 20 | Berries, full grown, light red | 5.33 | |
| 20 | Berries, full grown, dark red | 5.15 | .000007079N |
| 20 | Berries, black, soft ripe | 4.98 | .00001047N |

### TOMATOES

A very considerable amount of work was done in 1927 and 1928 on several varieties and types of tomato. The work was carried out along lines essentially identical with those followed by Gustafson in the work described in his 1928 paper (*18*), not then published. At intervals of 4 to 7 days fruit from blossoms tagged at opening was collected, and determinations were made of weight, hydrion concentra-

tion, water content, and chemical composition. The results confirmed Gustafson's statements as to the course of the changes in active acidity and water content; it therefore seems unnecessary to present the data in detail.

In general, the situation found to prevail in the other fruits herein studied holds for the tomato, namely, that increases in active acidity and in water content coincide in time and that the period of their rise is also that of the most rapid percentage increase in weight. It was discovered rather early in the study that these changes are not confined to a definite period in the life of the fruit but are so largely controlled by environmental factors that their occurrence may be delayed for several weeks or even until ripening changes are setting in. Study of this fact led to the further discovery that definite gradients in hydrion concentration and in water content between the several regions of the fruit are established early in the life of the fruit and are maintained throughout its development and maturation. The results of these studies are to be prepared for separate publication.

## DISCUSSION

The data presented in the foregoing sections presents in outline the course of changes in hydrion concentration occurring during development in a number of fleshy fruits, as well as on the accompanying changes in volume and composition and particularly in water content. The fruits employed were purposely chosen to include a wide diversity of types with respect to period of development, botanical relationships, and structure of fruit, and include true drupe or stone fruits, such as cherry and elderberry; aggregates, as the blackberry and raspberry; a torus (strawberry); a true berry (tomato); a compound berry (pokeberry); a hesperidium (orange, grapefruit); and a pome fruit (apple). In consequence, generalizations that are valid for the material in hand may reasonably be assumed to apply broadly to the fleshy fruits as a class.

Studies by various workers of the active acidity conditions at various seasons of the year in the vegetative and fruiting branches of a number of species have brought out the fact that there is in all perennial fruit trees a reduction of active acidity of the expressed sap to a minimum during the dormant period and a rather abrupt rise with the resumption of growth. In the lemon, Reed and Halma (*29*) found that active acidity increased from pH 6.15 to 5.40. Anderssen (*2*) found changes in the expressed sap of pear branches of about 0.4 pH, the reaction of the tracheal sap meanwhile increasing 0.7 pH in pear and 1.0 pH in apricot. In both cases the change was rather abrupt and the maximum values reached (pH 5.3 in pear, pH 5.4 in apricot) remained fairly constant for 2 to 3 months following full bloom, after which they slowly declined. Hooker (*22*) found that maximum active acidity in bearing, nonbearing, and barren spurs of apples occurred from March to June, then declined to a minimum during the fall and winter. Other workers have confirmed his results.

In all the fruits studied in the present work it appears that the young fruits at setting and for a variable but always brief period after enlargement begins are low in their active acidity. In the orange, grapefruit, apple, strawberry, and tomato, the hydrion-concentration values of the juices of the youngest fruits obtainable are of the same

order of magnitude, and in several instances practically identical with those obtained from juices of the fruit spurs, leafy branches, and other vegetative parts of the plant concerned. During this period the fruit is characterized by a high content of total solids consisting predominantly of insoluble materials. Variation in content of water is confined to a relatively narrow range, showing no rapid increase. In the cherry, blackberry, and dewberry there is an initial stage of high water content followed by a decrease which establishes a relatively high value for total solids.

This period of relatively stable conditions is succeeded by a period of markedly rapid increase in active acidity which is always of relatively short duration as compared to the entire life of the fruit. The increase in active acidity during this period varies widely among the various types of fruits herein studied. The greatest increase is found in the orange, where the increase is more than 5,200 percent; the smallest increase in the pokeberry, where it is but 250 to 400 percent. In most of the fruits for which the series of samples at all approaches completeness for the early stages, active acidity undergoes a rapid increase to a concentration 10 to 50 times that of the youngest fruits procurable. Any adequate explanation of this rapid rise in active acidity must await further investigation; the present study establishes the fact of its general occurrence in fruits of widely varying types.

The period in the life history of the fruit at which the most rapid change in active acidity occurs varies considerably in the different fruits. In fruits with a short developmental period, such as cherries, strawberries, and blackberries, the period of rapid increase in active acidity is practically the same as the period of the most rapid increase in size and culminates as the fruit begins to show indications of ripening. In apples, the increase in active acidity is practically completed when the fruit has attained one tenth to one eighth its normal size and weight at maturity. In citrus fruits, the period of rapid increase in active acidity is preceded and followed by a period of some length in which there is little change. In the tomato, the period of transition normally occurs about midway in the life history of the fruit but may be postponed until much later.

With the rapid increase in active acidity is associated a rapid and rather large increase in water content of the fruit, which usually begins to be evident shortly after the change in active acidity appears and which may continue to increase in rate after the rapid change in acidity has ceased, or may attain a maximum simultaneously with the attainment of maximum active acidity. In the apple and the citrus fruits the second of these situations prevails; the abrupt increase of active acidity is accompanied by an equally abrupt rise of water content of the fruit to a maximum. A similar situation exists in the cherry and in the strawberry. In both fruits the rise of active acidity is paralleled by a rapid accumulation of water in the tissues, which reaches a maximum simultaneously with the attainment of highest acidity. In the tomato, the concurrence in time between attainment of highest acidity and highest water content is not exact, as might be anticipated from the fact that each of the several regions has a characteristic hydrion concentration and water content. In all other fruits for which determinations of water content have accompanied hydrion-concentration determinations, there has been a striking concurrence in time of the upward trend of these values.

The period in which these changes are in progress is also the period of most rapid percentage increase in weight (figs. 2–5, 8). That the absorption of large amounts of water is chiefly responsible for the increase in total weight is immediately obvious from the sharp decline in percentage of total solids. It is only after the point of maximum water content is reached that the formation of new material begins to contribute to the weight of the fruit at a rate comparable to that of the absorption of water. That is, the period of most rapid growth is predominantly a period of absorption of water up to a maximum which is usually subsequently reduced somewhat by an increase in the rate of accumulation of solids as maturity of the fruit is approached. A rather significant fact with respect to this period of rapid hydration of the fruit, and one to which we shall return in the subsequent discussion, is that the degree to which hydration proceeds is very definitely correlated with the level of active acidity simultaneously developed in the tissues.

It has been pointed out repeatedly in the preceding sections that the most rapid gain in weight upon a percentage basis takes place simultaneously with the most rapid increase in active acidity and in water content, so that the steepest portions of the three curves coincide in time. Before the active acidity begins to change, the fruit is increasing its volume by the addition of solids and of water at approximately equal rates, with the result that the water-to-solids ratio remains fairly constant. In the period of changing acidity the rate of water intake exceeds that of accumulation of solids and the water-to-solids ratio rises. When active acidity ceases to rise, the rate of water intake decreases and may drop below the rate of accumulation of solids. It is probable that in developing plant parts in general the period of rapid cell enlargement is one in which rapid hydration of the tissues is in progress.

That the period of increase in water content does not depend upon any external factor such as occurrence of precipitation or amount of soil moisture is evident from the 1928 results. The month of May was subnormal in rainfall, and the soil was becoming distinctly dry on the 26th, when a rainfall of 1.11 inches occurred. There was no further precipitation until June 16, by which time the soil was again quite dry. The abrupt rise in water content in the early cherry occurred from May 15 to 20; that in the midseason variety, from May 21 to 28; that in the late cherry and the blackberry, about June 5 to 15. In strawberries and in a number of apples the increase in water content was well advanced before the occurrence of rain. That it is not a dilution effect resulting from a sudden increase in the water supply available to the plants is therefore clear. That the levels of water content reached in the apples Launette and Amère du Surville are markedly below those of the more highly acid Rambo, Baldwin, and Grimes Golden, despite the identity of their conditions as to rainfall and soil moisture supply, is also significant in this connection.

All the facts appear to point to the conclusion that the sudden increase in water content of the fruit is due to the development of a new force within the fruit which is powerful enough to draw water from the vegetative tissues regardless of the supply available to the root system.

That the mechanism here involved is one of swelling of hydrophilic colloids under the influence of progressive increase in active acidity

seems to be a conception in accordance with all the facts. The young fruit is exceedingly high in its content of hydrophilic colloids, since the protoplasmic proteins, cellulose, hemicellulose, pentosans, tannins, and protopectins are strongly hydrophilic. Although little is known of the isoelectric points of these individual constituents, it seems clear that for some of them the point of minimum swelling lies somewhere along the scale between pH 4 and the neutral point. The young fruit begins its development with a hydrion concentration approximating that of the vegetative tissues of the plant; that is, somewhere in the region pH 4.5 to 6.0. At this time it has a relatively low water content, which shows fluctuations of some magnitude, probably gaining or losing water to the vegetative tissues as these gain or lose in water content. As the active acidity of the fruit tissues begins to rise well above that of the vegetative tissues, the earlier process of give and take with respect to water becomes one of steady absorption into the fruit because of the greater magnitude of the force of imbibition exerted by the acid-swollen colloids and also because of the transformation of a considerable portion of the free water into bound water as it enters the tissues. That a physical force of large magnitude is active at this stage of development is evident from the fact that the young fruit is able to take large amounts of water from the vegetative parts. That the liquid present during the period of rapid increase in water content is largely held by the swollen colloids is evident from the fact that liquid can be expressed only with difficulty and is very highly viscous, setting to a gel after standing a few minutes. In the later stages of development these characters disappear.

Reed and Bartholomew (*28*) have called attention to the existence in young fruits of lemon, apple, and tomato of thick walls which give the reactions for pectose, and such histological studies as those of Tetley (*36*) have shown the existence of walls of this character in the apple. Reed and Bartholomew found that these young walls have marked imbibitory properties, swelling to such an extent when placed in water that their boundaries become indistinct. They are considered by Reed and Bartholomew as being important paths for the translocation of water, and these authors point out that the distribution of water between wall and protoplasm is an equilibrium between the imbibitional power of the cell wall and the suction pressure of the protoplast.

It would seem that we have here an approach toward an explanation of the paradox that the water content of a fruit reaches its maximum when soluble carbohydrates and other constituents capable of contributing to osmotic pressure are at a minimum and that it later decreases when soluble carbohydrates are rapidly accumulating. The water of the young fruit is bound by the colloidal micelles; the nonliving structural elements as well as the protoplasmic colloids, participate in the process insofar as their several isoelectric points lie below the levels of active acidity attained in the young fruit, so that the rise of acidity increases their imbibitional capacity. In forming this conception of the process it is not necessary to attribute a definite isoelectric point to the fruit as a whole (*13*, *30*, *31*, *37*) but merely to consider the known behavior of the several hydrophilic colloids present in the cells when they are isolated and treated with solutions of increasing hydrion concentration. Furthermore, the

mechanism is exactly that which is operative in maintaining the water level of the vegetative portions of the plant. The difference is that the active acidity of the growing fruit mounts to a level markedly higher than any recorded for the vegetative tissues of any nonsucculent, and is accompanied by a rise of water content to corresponding levels. In Hooker's (*22*) study of the bearing and nonbearing spurs of apple, there was a very rapid increase in water content to a maximum of about 65 percent in mid-May, concurrently with rise of active acidity to a maximum, followed by a progressive decline to less than 50 percent in midwinter. In barren spurs, which show a much smaller rise in active acidity, the rise in water content was very markedly less, only 52 to 54 percent (*22, fig. 1 and table 25*).

As already stated, the percentage of water taken up by the several fruits during the period of transition bears a rather direct relation to the degree of active acidity attained, being least in an apple of low maximum acidity (Launette, maximum pH 3.75, maximum water content 465 percent), intermediate in one of medium acidity (Amère du Surville, pH 3.43, maximum water content 594 percent), and closely approximating 700 percent in all the fruits, regardless of species or variety, in which active acidity rises to the level of pH 3.00. This very strongly suggests that a force of identical character is operative in all these cases, as would be true were the cell proteins and the pectose of the walls the chief agents concerned. The fact that water content rises to very considerably higher levels in the cherry, strawberry, and especially in the tomato than it does in the apple and the citrus fruits, notwithstanding the higher acidity of these last-named fruits, does not necessarily render this conception untenable. In any fruit the swelling of the hydrophilic colloids under the influence of a given degree of active acidity takes place against a mechanical resistance due to the structure of the fruit, which may limit the rate and determine the degree of the process. That such mechanical resistance may restrict the degree of hydration to a fairly uniform upper limit in fruits of essentially identical structure is suggested by the results with apples.[7] The higher degree of hydration found in strawberries and cherries may result from an anatomical structure offering less resistance to swelling or from a difference in the amount and character of the hydrophilic colloids concerned. In the tomato it is known that the jellylike pulp surrounding the seeds is a colloid having such enormous capacity for imbibing water that it holds 1,800 to 1,900 percent of its dry weight at a hydrion concentration of 4.10 to 4.39 (*23*).

Some fruits, as the Eureka lemon studied by Bartholomew and the native crab apple and the grapefruit, studied here, ultimately attain a very high active acidity by a gradual increase following the period of rapid rise. Such further increase is not attended by a corresponding rise in water held by the tissues, the water content remaining fairly stationary at a level no higher than that found in fruits very much lower in active acidity. This fact does not necessarily invalidate the theory that the swelling of hydrophilic colloids under the influence of increasing acidity is responsible for the earlier intake of water. The capacity of any colloid to swell under the influence of acids has an

[7] The breaking of drought during the growing period is often followed by general splitting of fruit. That certain varieties split badly, as Champion among peaches and Stayman Winesap among apples, under conditions that do not result in splitting in other varieties, may indicate an anatomical structure offering less mechanical resistance than that of other varieties, or a higher content of hydrophilic colloids.

upper limit beyond which further increase in the active acidity of the solution does not result in further absorption of water. In the fruits herein discussed this upper limit appears to be near pH 2.8 to 3.0. Increase in water content continues with increasing acidity up to somewhere near this value, then practically ceases in those fruits (grapefruit, native crab apple, and lemon) in which acidity rises to higher levels.

It has already been pointed out that the water content of the fruit usually decreases somewhat from the maximum attained during the rise of acidity, and that the amount of this decrease is in general broadly parallel with the decrease in hydrion concentration which is occurring during the same period. Aside from the decrease in water-holding capacity of the colloids which would result from reduction of acidity, at least two other factors may be involved in this change. The proportion of living protoplasm to the total bulk of the fruit continually decreases as later development proceeds. This is true in even greater degree of the nonliving cell-wall constituents, namely, the hemicelluloses, pectins, and tannins and related substances, which not only cease to increase in relative amount but undergo a very considerable decrease through conversion to simpler products, including sugars, as maturity approaches. This progressive decrease in amount of both living and nonliving colloidal material may play a considerable part in the reduction of water content of the fruit as it approaches maturity, and may account for the fact that the vegetative tissues withhold or even withdraw water from the fruit in periods of insufficient water supply, as observed by Bartholomew (*5*) in lemons and by Furr and Magness (*14*) in apples. In fruits in which there is rapid accumulation of sugar as the fruit ripens, there may be a final rise in water content for which the increasing osmotic pressure of the cell solution is responsible.

Concurrently with the shift to higher levels of active acidity and of water content there is an increase in total titratable acidity, which occurs at a much less regular rate and during a much less definite period. This increase was observed in every fruit studied, with the exception of two of the apple varieties for which the series of samples was lacking in early stages, so that its occurrence in these varieties at a period prior to the beginning of sampling is a possibility. There was no relationship between the increase in active acidity and that in titratable acidity as regards amount and only a very general relation as regards time; one may be stationary or decreasing at the time of the most rapid increase in the other. In the grapefruit of table 3, for example, titratable acidity increased very little from October 1 to November 21, a period in which the concentration of active acidity in the pulp increased more than threefold.

The period of transition from the plane of low active acidity and low water content in all the fruits studied is one of low and rather constant values for sugar content, and the sugar present is predominantly in the form of reducing sugar. During this period, sugar is used up in the construction of new tissues almost as rapidly as it is transported into the fruit. At the close of the transition period accumulation of sugar begins. In the apple the initial increase is primarily in reducing sugars, followed later by increase in sucrose; in the orange and grapefruit there is a rather sudden increase, due almost wholly to increase in sucrose; in strawberries, blackberries, and cherries

the increase in sugar content is almost wholly in the form of reducing sugars and the sucrose content may even decrease as the fruit matures. These facts at least suggest that carbohydrate may be transported into the fruit in the form of reducing sugars and that in the short-lived fruits there is no subsequent conversion to sucrose, though such conversion occurs in the slow-maturing fruits such as apple and citrus.

The period of later development following that of rapid change varies greatly in length but is marked by the same general sequence of events. In the citrus fruits this period lasts several months. At the beginning of this later period active acidity fluctuates somewhat, with a tendency to increase slightly; later it becomes relatively stationary; and then slowly decreases as the fruit approaches picking maturity. Water content fluctuates somewhat irregularly, as would be anticipated from Bartholomew's (4) discovery that water is withdrawn from the fruit into the vegetative organs whenever there is a deficiency of available soil water, but shows a clear tendency to remain somewhere near the general level established in the transition period. The rate of increase in total weight decreases rather sharply at the outset of the period, the curve becoming nearly a straight line (fig. 6). Total solids in the orange and grapefruit show a progressive decrease which at first is rapid as a result of decrease in insoluble solids, the soluble solids meanwhile remaining nearly stationary. The rate of decrease of total solids later becomes slow because gains in soluble solids nearly or quite offset the slow decrease in insoluble solids. Astringency shows a rather irregular course, but there is a considerable net decrease. Titratable acidity declined markedly in the orange, but remained unchanged in the grapefruit up to the end of the period of sampling, which, unfortunately, was terminated by circumstances before the fruit had become tree ripe.

In the apple the changes during this period are in broad outline identical, the chief differences being that active acidity declines very considerably, more than is the case in any of the citrus fruits, the curve of rise and decline showing in all varieties the mountain-peak character indicated in the graphs (figs. 2, 3, and 4). It is notable that water content in all cases drops from the maximum attained in the transition period to somewhat lower levels, and that the curve of change in water content roughly parallels that of change in active acidity, taking the same mountain-peak outline. Total solids show a slow and somewhat variable increase, as increase in soluble solids and decrease in insoluble solids vary in their relative rates throughout the period.

In the strawberry and the cherry there is a rather sharp decline in water content as sugar accumulates in the ripening fruit. In both fruits this decline is preceded by a period in which both active acidity and water content are nearly constant; afterward both decline, the decrease in water content preceding the decrease in acidity. In these respects the varieties represented in the graphs are quite in accord with the others dealt with in the work.

## SUMMARY

In a large number of the fleshy fruits, including oranges, grapefruit, apples, strawberries, blackberries, raspberries, elderberries, pokeberries, and cherries, the young fruits at setting and for a short period

thereafter have a hydrion concentration rather close to the general level found in the vegetative parts and fruiting structures of their respective plants. During this period of low acidity the fruit has a high solids content. Morphologically it is the period in which rapid and general cell division is in progress.

This period is succeeded by a period of transition, always of short duration, as compared with the entire developmental period of the fruit, in which the active-acidity content of the young fruit very rapidly rises from the low values of the vegetative structures to the high values of the developing fruit. In the fruits herein discussed, this increase in active acidity ranges from less than tenfold in strawberries to more than eightyfold in the citrus fruits.

Concurrently with the beginning of the rise in active acidity or soon afterward, the fruit begins to absorb water at a rapid rate, so that the percentage of solids is reduced and the fruit attains a condition of maximum hydration. This condition is reached simultaneously with the attainment of maximum active acidity or very shortly thereafter. The degree to which hydration proceeds during this period is very definitely related to the degree of active acidity developed.

The period of rapid rise in active acidity and in water content coincides with the period of the most rapid percentage increase in weight and volume. The three curves representing (1) increase in active acidity, (2) increase in water content, and (3) rate of percentage increase in weight begin to rise simultaneously, or nearly so, and swing upward together. With the attainment of maximum values for active acidity and water content, however, there is a very marked decrease in the rate of percentage increase in weight.

The consistent relationship found to exist between rate of growth and changes in active acidity and water content in fruits of widely dissimilar morphological character and length of life very strongly suggests that the rapid increase in active acidity may bear a causal relation to the period of the most rapid percentage increase in weight. The very large alteration in hydrion concentration markedly increases the imbibitional capacity of the protoplasmic colloids and of such cell-wall constituents as the pectins, which have isoelectric points well below the levels of active acidity here encountered. There is thus set into action a force capable of attracting and holding considerable quantities of water. The magnitude of this force increases with increase in hydrion concentration, thus accelerating the rate of water intake and of increase in weight and volume; the period of most rapid growth (on the percentage basis), therefore, is also a period of progressively increasing hydration.

After rising abruptly to a maximum, active acidity ceases to increase and remains nearly stationary for a period which varies in length for the different fruits. Water content also ceases to increase and remains nearly stationary. The point at which active acidity and water content cease to rise coincides in time with the marked flattening of the curve of percentage increase in weight.

From this point onward there is little or no increase in the protoplasmic colloids, and the formation of primary cell walls ceases. Consequently, the amount of material capable of marked swelling in the presence of acids becomes relatively stationary or begins to decrease. Moreover, the decline of metabolic activity results in a

lessened production of acids, as shown by a decrease in the hydrion concentration of the tissues. With a decrease in the active acidity of the cell sap and a cessation of formation of substances capable of strong swelling under the influence of acids, the fruit is no longer able to maintain the highly hydrated condition; later development is accompanied by a progressive decline in water content closely paralleling the decline in active acidity, which continues to picking maturity.

A working hypothesis is presented, namely, that variations in water absorption by the hydrophilic colloids of the young fruit, caused by changes in hydrion concentration of the tissue fluids, may be a factor of prime importance in determining the form and slope of the growth curve of the fruit. Although this hypothesis may require modification when more detailed studies have been made of the early stages of growth in fruits, at present it appears to offer an explanation of all the known facts.

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# BIOLOGY AND CONTROL OF TREE HOPPERS INJURIOUS TO FRUIT TREES IN THE PACIFIC NORTHWEST

BY

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UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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By M. A. YOTHERS, *associate entomologist, Division of Fruit Insects, Bureau of Entomology*

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## INTRODUCTION

In recent years considerable injury has been done to young orchard and nursery trees in certain parts of the Pacific Northwest by the egg-laying activities of various species of Membracidae, commonly known as "tree hoppers." This injury was of such importance that life-history studies and control experiments were begun at the Yakima, Wash., laboratory of the Bureau of Entomology in 1923 and continued until 1928.[1] The present bulletin gives the results of these biological studies, orchard observations, and control experiments.

Until quite recently the tree hoppers in orchards of the Pacific Northwest have been referred to indiscriminately by both entomologists and orchardists as the "buffalo tree hopper", although Wilson (*31*)[2] in 1915 and Lovett (*18*) in 1923 reported on certain other species. During the course of the author's studies, however, it developed that there are present in Washington, Oregon, and Idaho 15 or more

[1] The observations on *Heliria rubidella* were made at Wenatchee, Wash., from 1928 to 1932, with the assistance in 1930–32 of Paul B. Allen, Jr.

[2] Italic numbers in parentheses refer to Literature Cited, p. 44.

species of the genera *Stictocephala* and *Ceresa*, of which *S. inermis* Fab., *C. basalis* Walk., and *C. bubalus* Fab. are the more common and the ones responsible for the injury to fruit trees.

Studies and control experiments were confined largely to *S. inermis* and *C. basalis*, with minor observations on *C. bubalus*, *C. albidosparsa* Stål, and *Heliria rubidella* Ball.

The normal food plants of the tree-hopper nymphs appear to be certain succulent herbaceous plants and not fruit trees. Hodgkiss (*17*), in discussing the Membracidae in general, states that the young stages require more succulent foods. He reared nymphs through the earlier stages on young apple and pear trees, but in their later stages they became restless and were then fed upon other succulent, tender plants, principally the thistle.

## STICTOCEPHALA INERMIS FAB.

### DISTRIBUTION

*Stictocephala inermis* is the most common of all the membracids found in the orchards of the Pacific Northwest. It is probably more or less generally distributed throughout the States of Washington, Oregon, and Idaho wherever suitable environmental conditions prevail. Where acceptable food plants and suitable wood for the deposition of eggs are present and where climatic factors are favorable, as in the orchards of the arid districts, in which cover crops of alfalfa are grown, it becomes sufficiently abundant to be of economic importance.

This species is found generally throughout most of the United States, except in the Southeast, and is also present in the Canadian Provinces bordering on the United States.

### SYNONYMY AND COMMON NAME

This species was originally described by Fabricius (*7, p. 677*) and placed in his genus *Membracis* in 1775. In 1830 Say (*24, p. 243*) described it as *goniphora* of the same genus. Fitch, in 1851 (*11, p. 48*), referred *inermis* Fab. to the genus *Smilia* of Germar. Walker (*29, p. 1141*), in 1852, placed Say's species in the genus *Ceresa* of Amyot and Serville. In 1869 Stål (*26, p. 246*) placed *inermis* in his new genus *Stictocephala*. Rathvon (*23, p. 551*) in the same year used the same specific determination but placed it in Germar's *Smilia* (misspelled as *Smillia*). Since Uhler (*27, p. 471*), in 1871, placed the species back in the genus *Stictocephala* of Stål (spelling it as *Stictocephalus*) it has retained that classification.

The more important discussions of *inermis* are by Hodgkiss (*17*), Funkhouser (*12, 13*), and the writer (*32, 33, 34*). This species was under discussion by the writer (*32*) under the name of *pacifica* Van Duzee.

*Stictocephala inermis* has been called the "green clover tree hopper" by the writer (*33*) and others.

The more important synonymy is as follows:

*Membracis inermis* Fabricius, 1775 (*7, p. 677*)
*Membracis goniphora* Say, 1830 (*24, p. 243*)
*Smilia inermis* Fitch, 1851 (*11, p. 48*)
*Ceresa ? goniphora* Walker, 1852 (*29, p. 1141*)
*Stictocephala inermis* Stål, 1869 (*26, p. 246*)
*Smillia inermis* Rathvon, 1869 (*23, p. 551*)
*Stictocephalus inermis* Uhler, 1871 (*27, p. 471*)

## FOOD PLANTS

In the Northwest the author has found the nymphs of *S. inermis* almost exclusively on alfalfa (*Medicago sativa*), and in the earlier stages they are invariably found as far down within the crown of the alfalfa plants as they can get. At such points the plant is succulent, direct sunlight is cut off, and the maximum humidity prevails. Some have been found upon sweetclover (*Melilotus* spp.), and a few in the earlier stages have been found feeding on dandelion (*Taraxacum officinale*) and upon a species of wild mustard. In one infested orchard in which there were scattering alfalfa plants, all of which were heavily infested, extensive sweeping failed to reveal the presence of any of the insects in a thick growth of green foxtail (*Setaria viridis*). Funkhouser (*12*) records this tree hopper as common on sweetclover and red clover (*Trifolium pratense*) and occasionally on timothy (*Phleum pratense*). Essig (*6, p. 205*) regards it as common and often injurious to grasses, alfalfa, sweetclover, and other forage plants and weeds. Since alfalfa is an introduced species, it is obviously not the original food of this tree hopper, and the insect must have transferred its attention to this plant in recent years. Nymphs placed by the author upon opening apple leaf buds fed upon them to a certain extent, but all died within 9 days.

## CHARACTER AND IMPORTANCE OF INJURY

The injury to fruit trees caused by *Stictocephala inermis* is the result of the numerous punctures made in the bark and outer wood in the process of egg laying. Twigs in which eggs have been laid have a characteristic roughened, ragged appearance (pl. 1, *A*, *B*, and *D;* pl. 6, *A*, *c*).

Most of the egg laying is done in the older wood of the previous season's growth, but the roughened condition persists for 2 or 3 years, after which time the curled fragments of bark wither, leaving only the deeper wounds and healed scars, giving the bark a slightly lumpy appearance. On peach twigs, injury by *S. inermis* causes gum to ooze from the wounds. This gum hardens into a dark, brittle exudate, giving the bark the appearance shown in plate 1, *C*.

The injury caused by this species occurs rather generally in apple and pear orchards in the Pacific Northwest wherever alfalfa is grown as a cover crop, occasionally in peach and willow trees, and on rare occasions in prune and poplar. The injury is particularly important in 1-year-old and 2-year-old apple and pear trees. In older trees the injury is largely confined to the twigs or smaller branches within 6 or 7 feet of the ground, especially where the branches hang well down into or toward the alfalfa.

The nymphs cause moderate injury to alfalfa by sucking out the plant juice in such a manner as to give the stems a girdled appearance (pl. 2, *C*). Wildermuth (*30*) has described similar injury to alfalfa by *Stictocephala festina* Say, but in the Northwest the damage done by *S. inermis* and other species to alfalfa has been found by the writer to be comparatively unimportant.

## DESCRIPTION OF STAGES

### THE EGG

The egg (fig. 1, *A*) is about 1.5 mm in length and 0.4 mm in diameter. White, apex slightly pink; roughly cylindrical, compressed latterly toward apex, broadly expanded below, bluntly rounded at the base; margins more or less curved; chorion vitreous, transparent.

### THE NYMPH

The nymphs have much the same general shape as do the adults, but the body, instead of being covered by the prothoracic shield, is covered with many tuberosities, spines, and hairs. There is 1 pair of these dorsal tuberosities on the head, 2 pairs on the prothorax, 1 pair each on the mesothorax and metathorax, none on the first abdominal segment, but 1 each on the 7 succeeding abdominal segments.

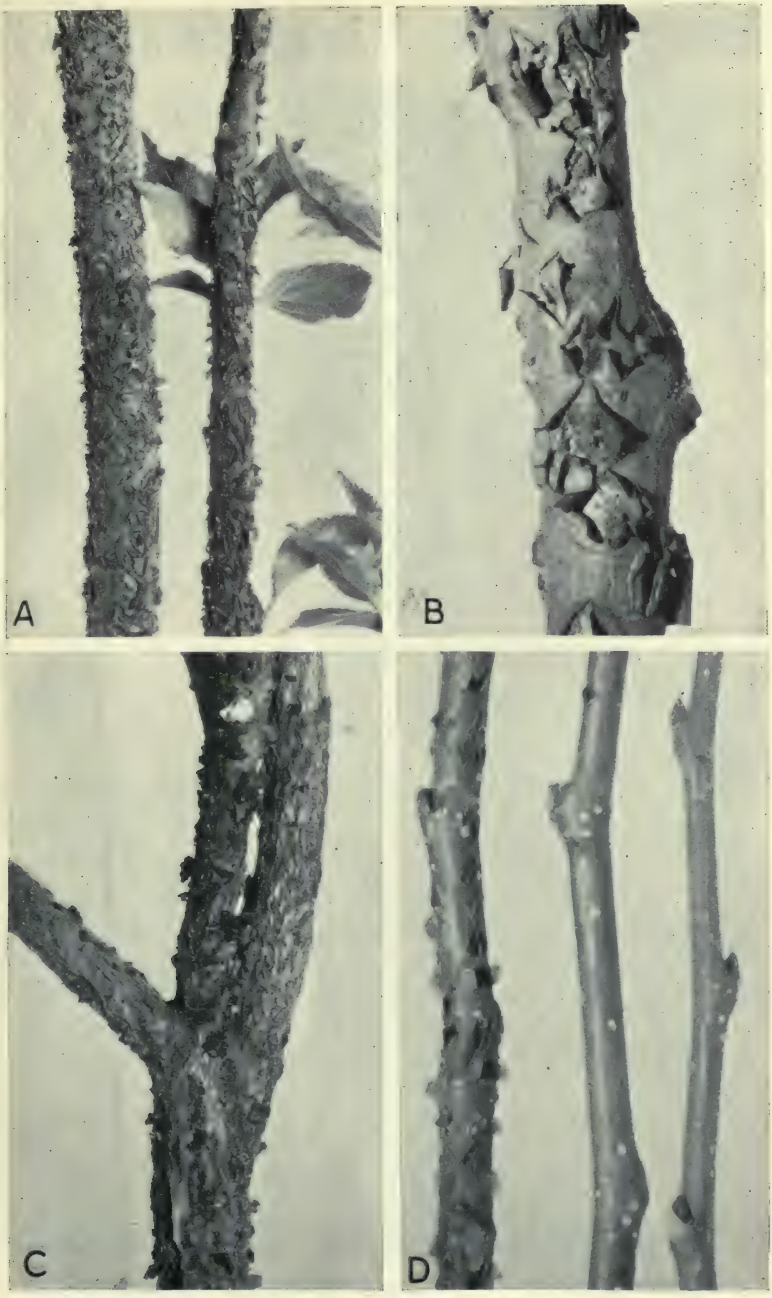
The number of tuberosities does not appear to be specific, as Wildermuth (*30*) figures the same for *S. festina* and Hodgkiss (*17*) describes the same number of tuberosities for *C. bubalus*, *C. taurina* Fitch, and *C. borealis* Fairm. The general appearance of the nymphs remains about the same throughout the five instars, except that in the first the dorsal tuberosities have but a single subspine, whereas later instars have multiple-branched tuberosities. Also, of course, the wing pads develop during the fourth and fifth instars (fig. 1, *E* and *F*).

### DESCRIPTION OF INSTARS

*First instar* (fig. 1, *B*).—Length 1.5 to 2 mm. Head compressed cephalocaudad, oblique and rounded in front, mouth parts directed backward and reaching the middle of the second abdominal segment. Eyes white with dark center from which arise three stout, simple hairs. One pair of unbranched tuberosities on apex of head, ending in long, slender, slightly recurved hairs; several pairs of hairs on head and face, those on the upper part of the head curving upward, those on the face curving downward. Prothorax with two pairs of tuberosities, the front pair unbranched, the second pair with a single stout spine in addition to a long spine terminating each tuberosity. Mesothorax with a single pair of tuberosities with two short spines branching off (fig. 2, *A*, *a*). Metathorax with a single 1-branched tuberosity. First abdominal segment with no tuberosity, but instead a small, simple hair. Succeeding abdominal segments each with a pair of single-spined tuberosities in addition to the long hair terminating each, sloping and curling caudad, overlapping the succeeding one. Anal tuberosity smaller and with two short spines at its base. Three or four hairs on either side of each thoracic and abdominal segment. Hairs fringing end of anal segment. Color: White when first hatched, but after an hour or so turning to pale straw color and then to purplish brown on head and part of thorax and abdomen, body generally hyaline, tuberosities slightly suffused. Legs pale.

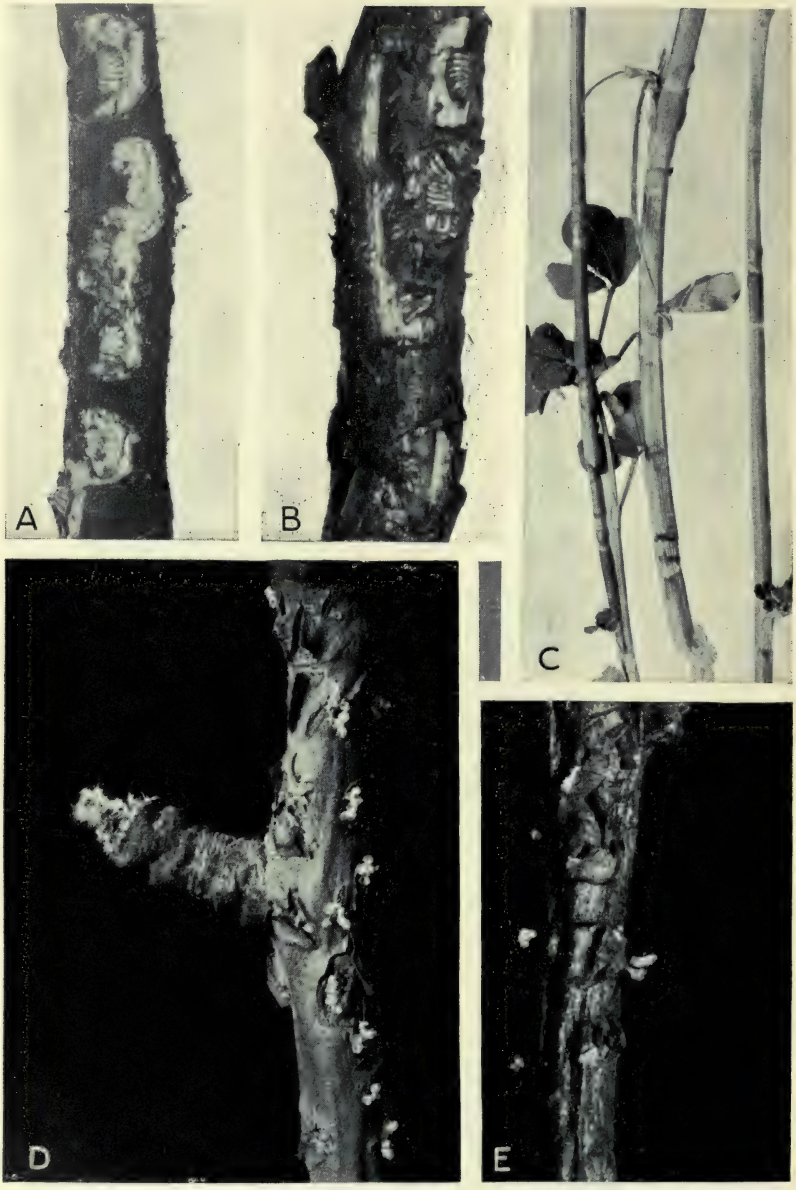
*Second instar* (fig. 1, *C*).—Length 2.5 to 3 mm. Head compressed cephalocaudad, rounded, spinose, reaching to the first abdominal segment. Tuberosities complex. Eyes supporting three hairs, single pair of complex tuberosities at apex of head with two branches, hairs on face and head as in first instar. Prothoracic tuberosity with 4 subspines (fig. 2, *C*). Mesothoracic, metathoracic and abdominal (fig. 2, *D*) dorsal tuberosities each with from 6 to 7 subspines, except anal tuberosity, which has but 2. More median hairs on sides of segments throughout. Anal tube fringed with spines and hairs. Color: Body generally hyaline; head and prothorax darker than in first instar, especially along dorsum and at spots along sides and on legs.

*Third instar* (fig. 1, *D*).—Length 3.5 to 4.5 mm. Head somewhat compressed cephalo-caudad, but less than in earlier instars. Tuberosities and hairs on head as before. Prothoracic subspines large, 6 in number, and stout (fig. 2, *E*). Mesothoracic, metathoracic, and abdominal tuberosities with about 10 subspines each (fig. 2, *F*). Tuberosity subspines intermingling. Abdominal tuberosities curving backward, last pair not reaching the anal pair, which are smaller and with only 3 or 4 subspines. Thoracic and abdominal hairs short and stout. Body spinose. Color: Hyaline to pale greenish on head, dorsum, and spots along sides. More color than in preceding instars.




INJURY TO FRUIT TREE TWIGS BY STICTOCEPHALA INERMIS.

A, Apple twigs showing characteristic shaggy, roughened appearance caused by the oviposition wounds. × ⅔. B, The same, twice natural size. C, Injury to young peach tree showing protruding particles of dark, brittle exudate formed by the sap oozing from the wounds. × ¾. D, Characteristic curling back of outer bark at oviposition scars in pear twigs. × ⅔. Note that only two scars appear in the newer wood in the center and none in the still younger growth at the right.




A and B, Egg pouches of *Stictocephala inermis* with bark removed showing the arrangement of the eggs. × 1.6. C, Alfalfa stems showing scars caused by the feeding of nymphs of *S. inermis* confined in rearing cages. × ¾. D, Empty hatching membranes protruding from egg pouches of *S. inermis*. × 1.3. E, Nymphs of *S. inermis* issuing from eggs in apple twigs. × 1.3.

*Fourth instar* (fig. 1, *E*).—Length 5 to 5.5 mm. Head compressed cephalocaudad, but less than before. Eye spines several. Body curved, spinose. Mouth parts horizontal, reaching to metathorax only. Wing pads conspicuous.

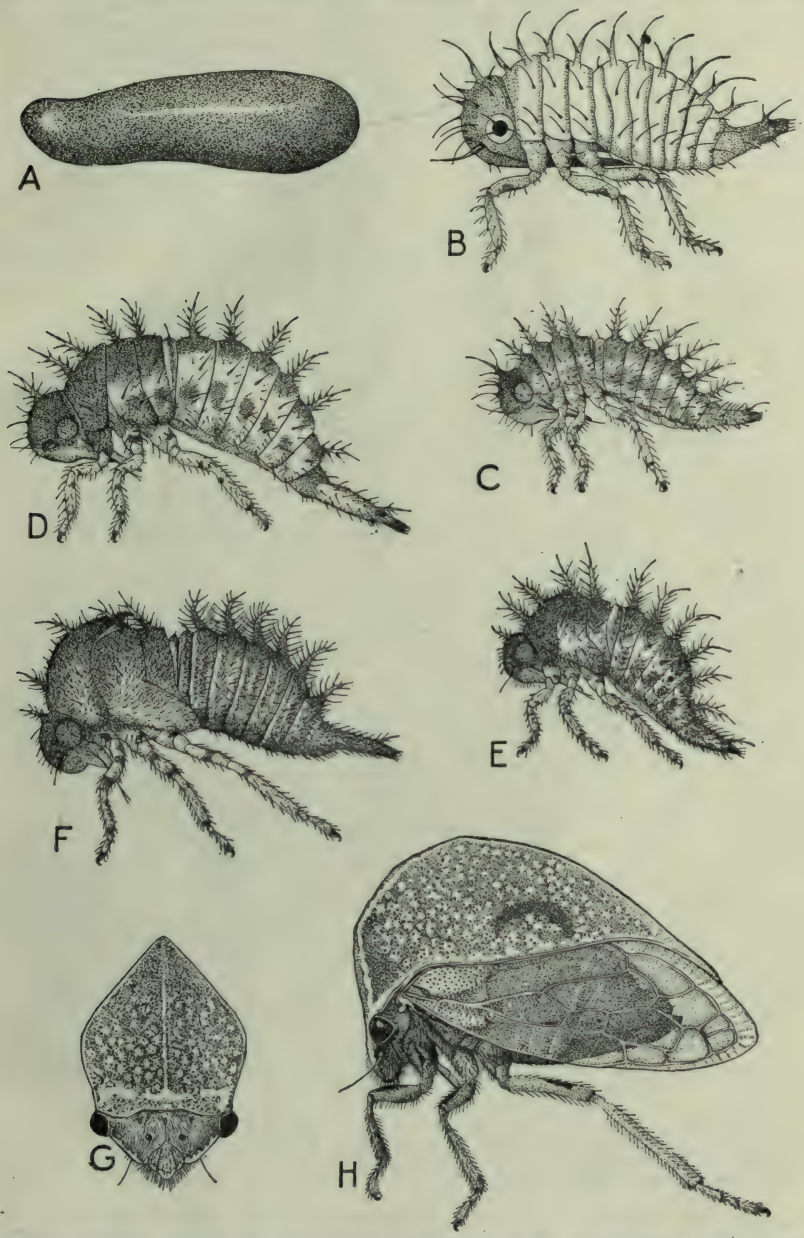



FIGURE 1.—Successive stages in the development of *Stictocephala inermis:* A, Egg, ×30; B-F, first to fifth nymphal instars, B×25, C×13, D×15, E×7, F×7; G, adult, front view, ×7; H, adult, side view, ×7.

Thoracic and abdominal tuberosities with 15 to 22 subspines (fig. 3, *A* and *B*), tuberosities broader at base, extending the whole width of segment. Abdominal tuberosities strongly curved caudad, subspines intermingled. Color: Brownish

testaceous on head, dorsum, and median part of thorax, with spots of brown on each abdominal segment. Tuberosities somewhat suffused.

*Fifth instar* (fig. 1, *F*).—Length 7 to 8 mm. Head compressed caudad, but less than formerly. Ventose. Eye spines numerous. Prothorax strongly elevated, keel sharply rounded; hooked, spinose. Thoracic tuberosities leaning forward, abdominal tuberosities leaning forward but curving strongly backward.

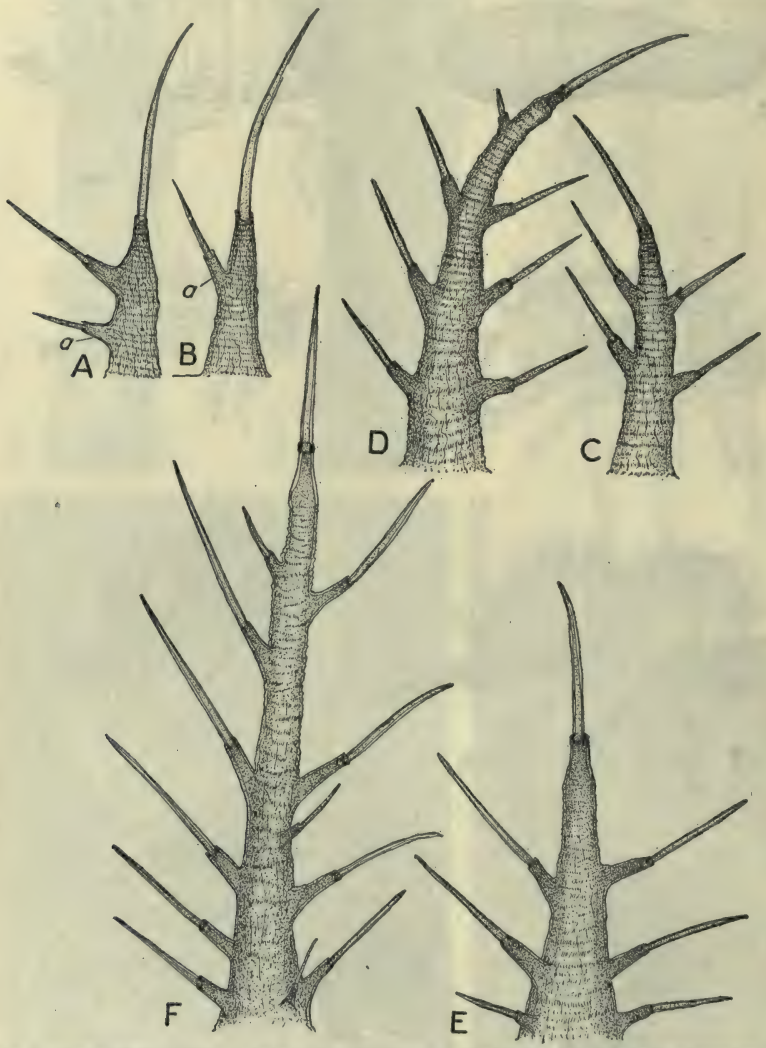



FIGURE 2.—Dorsal tuberosities of *Stictocephala inermis: A*, First-instar mesothoracic tuberosity with extra subspine (*a*); *B*, *a*, all other tuberosities in the first instar have a single subspine as in the metathoracic tuberosity; *C*, second-instar prothoracic tuberosity; *D*, second-instar dorsal abdominal tuberosity; *E*, third-instar prothoracic tuberosity; *F*, third-instar dorsal abdominal tuberosity. Greatly enlarged.

Subspines intermingled, numerous, 20 to 25 on each tuberosity (fig. 3, *C*). Body spinose. Wing pads conspicuous, reaching second abdominal segment. Color: Head, part of pronotum, dorsum, venter, and spots along sides faintly testaceous to pale green, otherwise hyaline. Tuberosities faintly suffused.

### THE ADULT

*Description of adult* (pl. 4, *B*; figs. 1, *G*, *H*, and 14, *B*).—Length 7.5 to 9 mm. Head broad, nearly smooth, very finely and faintly punctate, face closely striate

between ocelli and eyes. Clypeus and lora short and rounded at the apex. Metopidium perpendicular, dorsal crest high and arcuate, widening above to rounded superhumerals. Tegmina and wings entirely hyaline. Upper part of femora generally black, sometimes this marking absent. Pronotum densely but closely punctate, metopidium convex, median carina distinct but irregular; sides of metopidium meeting before the middle of the body; posterior processes long, slender, gradually acuminate, curving downward, extending beyond abdomen. Segments of abdomen in some cases bordered with black. Last segment of abdomen of female broadly angular. Color: Brilliant green to yellowish.

## LIFE HISTORY AND HABITS

In common with the other tree hoppers herein discussed, *Stictocephala inermis* hibernates in the egg stage in the bark of fruit trees (pl. 2, *A*, *B*). These hatch in early spring, the nymphs mature by

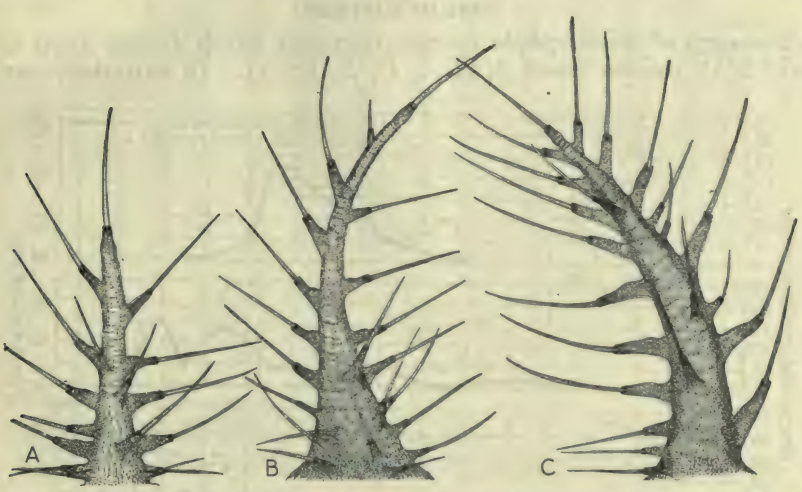



FIGURE 3.—Dorsal tuberosities of *Stictocephala inermis: A*, Fourth-instar prothoracic tuberosity; *B*, fourth-instar dorsal abdominal tuberosity; *C*, fifth-instar prothoracic tuberosity. Other tuberosities in the fifth instar turn caudad. Greatly enlarged.

early summer, and the adults lay their eggs during the middle and latter part of the summer. There is one generation a year.

The studies here recorded were carried on at Yakima, Wash., in 1923, 1924, and 1925, with occasional observations in 1926, 1927, and 1928. Many observations were made in the orchards, others in the insectary, some in rearing cages placed over alfalfa plants, and still others in larger cages placed over alfalfa plants and small fruit trees (pl. 3, *A*, *B*)

### METHOD OF STUDY

Each season before hatching began, twigs containing eggs were placed with their cut ends in jars of water. Some were allowed to remain in the laboratory, where the temperature ranged from 40° to 75° F.; others were placed in the insectary at out-door temperatures. When the eggs began to hatch in the insectary, it was time to make observations in the orchards. After the first season it was not difficult to foretell at about what time hatching would commence.

When hatching began, representative samples of twigs containing eggs were brought from the orchard to the insectary, where they were

kept with their cut ends in bottles or jars of water. The nymphs emerging from these fell upon the paper-covered table, where they were counted hourly throughout the hatching season. Each day individuals were placed in lantern-chimney cages on potted alfalfa plants 2 to 4 inches high. These individuals were examined daily, or often enough to check on the molting process. After the first season the weak, pale alfalfa plants growing under the lantern chimneys were supplemented with freshly gathered succulent alfalfa sprouts. All individuals not used in the studies of molting in the lantern-chimney cages were transferred to the large cages placed over normal alfalfa plants in the insectary yard. General observations were made on these to check against material reared in the insectary and under observation in the orchard.

### DATE OF HATCHING

The eggs of *Stictocephala inermis* normally hatch during April and early May (tables 1 and 2; pl. 2, *D*, *E;* fig. 4). In extremely early

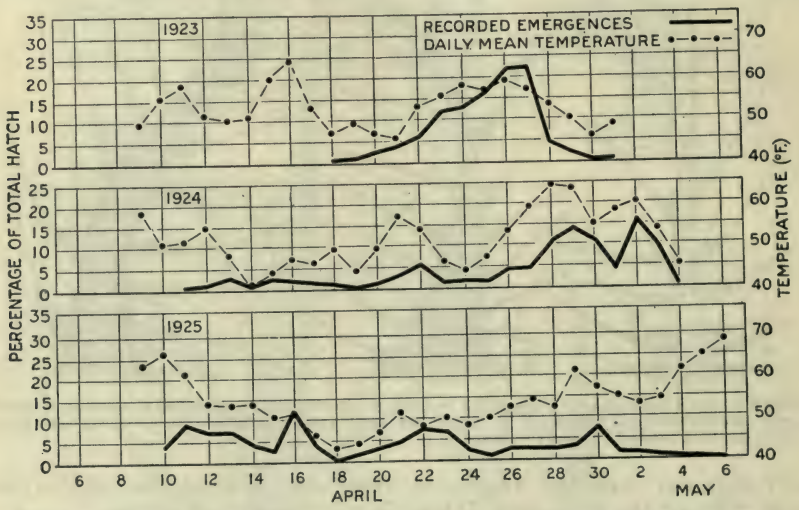



FIGURE 4.—Hatching of eggs of *Stictocephala inermis* in relation to temperature, Yakima, Wash.

seasons, as in 1926, hatching may start as early as the last of March, whereas in extremely late seasons, as in 1927, it may not start until late April. The time of hatching is apparently intimately correlated with bud and blossom development of the fruit trees in the orchards. In the 6 years from 1923 to 1928, inclusive, while these insects were being observed, the hatching invariably commenced when the Winesap blossom buds were in the stage known as "the pink", just preceding the opening of the blossoms. The most favorable weather for hatching appeared to be when the mornings were warm, with a relatively high humidity, preceded by a night of the same character.

The hatching period is much shorter if continuously favorable weather conditions prevail, as in 1923, when the entire hatching period lasted only about 2 weeks (table 1). If interrupted by unfavorable weather conditions, the hatching period may be extended to a month, as occurred in 1925.

TABLE 1.—*Summary of the hatching of eggs of Stictocephala inermis in the insectary, and the relation to temperature, 1923, 1924, and 1925, Yakima, Wash.*

| Date | Eggs hatched | | | Temperature | | | | | | | | | Precipitation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1923 | | | 1924 | | | 1925 | | | | | |
| | 1923 | 1924 | 1925 | Min. | Max. | Mean | Min. | Max. | Mean | Min. | Max. | Mean | 1923 | 1924 | 1925 |
| | *No.* | *No.* | *No.* | *° F.* | *° F.* | *° F.* | *° F.* | *° F.* | *° F.* | *° F.* | *° F.* | *° F.* | *Inch* | *Inch* | *Inch* |
| Apr. 9 | | (1) | | 32 | 66 | 49 | 40 | 74 | 58 | 48 | 80 | 63 | | | |
| Apr. 10 | | | [2] 137 | 41 | 69 | 56 | 39 | 64 | 51 | 53 | 80 | 66 | | | |
| Apr. 11 | | 6 | 373 | 48 | 72 | 58 | 35 | 67 | 52 | 56 | 69 | 61 | | | T |
| Apr. 12 | | 15 | [3] 310 | 40 | 62 | 52 | 47 | 68 | 55 | 38 | 66 | 54 | T | | |
| Apr. 13 | | 36 | 309 | 36 | 64 | 50 | 40 | 60 | 47 | 35 | 68 | 53 | | | |
| Apr. 14 | | 11 | 190 | 35 | 68 | 51 | 34 | 52 | 41 | 44 | 64 | 54 | | | |
| Apr. 15 | (1) | 40 | 101 | 45 | 75 | 60 | 35 | 55 | 44 | 48 | 54 | 50 | | | 0.36 |
| Apr. 16 | | 29 | 482 | 49 | 78 | 64 | 34 | 62 | 47 | 43 | 63 | 51 | | | .15 |
| Apr. 17 | | 20 | 160 | 50 | 57 | 53 | 30 | 59 | 46 | 34 | 58 | 46 | 0.08 | | .02 |
| Apr. 18 | 4 | 17 | 0 | 34 | 63 | 47 | 39 | 58 | 49 | 37 | 46 | 43 | | | .06 |
| Apr. 19 | 5 | 1 | 69 | 33 | 60 | 49 | 32 | 57 | 44 | 32 | 58 | 44 | T | | T |
| Apr. 20 | 34 | 23 | 125 | 42 | 59 | 47 | 33 | 65 | 49 | 35 | 59 | 47 | .08 | | T |
| Apr. 21 | 44 | 44 | 202 | 32 | 59 | 46 | 35 | 75 | 57 | 40 | 64 | 51 | T | | T |
| Apr. 22 | 73 | 81 | 321 | 41 | 65 | 53 | 46 | 65 | 54 | 33 | 60 | 48 | T | | T |
| Apr. 23 | 154 | 16 | 289 | 43 | 69 | 56 | 37 | 57 | 46 | 37 | 61 | 50 | | | |
| Apr. 24 | 177 | 26 | 79 | 42 | 73 | 58 | 27 | 59 | 44 | 35 | 56 | 47 | | | |
| Apr. 25 | [4] 215 | 22 | 41 | 38 | 76 | 57 | 26 | 65 | 47 | 41 | 60 | 50 | | | |
| Apr. 26 | 292 | 65 | 104 | 38 | 77 | 59 | 29 | 71 | 53 | 39 | 64 | 52 | | | |
| Apr. 27 | 297 | 72 | [5] 100 | 47 | 66 | 57 | 38 | 77 | 59 | 40 | 67 | 54 | | | |
| Apr. 28 | 57 | 167 | 100 | 40 | 65 | 54 | 46 | 76 | 64 | 32 | 70 | 52 | | | |
| Apr. 29 | 20 | 204 | 154 | 44 | 58 | 50 | 52 | 76 | 63 | 40 | 79 | 61 | | | |
| Apr. 30 | 0 | 179 | 323 | 32 | 56 | 46 | 41 | 69 | 55 | 44 | 67 | 57 | | 0.02 | |
| May 1 | 3 | 67 | 74 | 35 | 59 | 48 | 39 | 76 | 58 | 45 | 71 | 55 | T | | |
| May 2 | | 239 | 52 | | | | 47 | 78 | 60 | 41 | 68 | 53 | | | |
| May 3 | | 150 | 28 | | | | 39 | 66 | 53 | 39 | 68 | 54 | | | |
| May 4 | | 1 | 18 | | | | 33 | 58 | 45 | 47 | 77 | 61 | | T | |
| May 5 | | | 16 | | | | | | | 50 | 82 | 65 | T | | |
| May 6 | | | 2 | | | | | | | 52 | 85 | 68 | | | |
| Total | 1,375 | 1,531 | 4,159 | | | | | | | | | | .16 | .02 | .59 |

[1] Winesap blossom buds in early pink stage.
[2] Hatching already in progress in the field for at least 2 days.
[3] Total for Apr. 13 divided equally with Apr. 12. (Estimate.)
[4] Apples in full bloom.
[5] Total for Apr. 29 divided with Apr. 27 and 28. More is estimated for Apr. 29 owing to higher temperature.

TABLE 2.—*Hatching of eggs of Stictocephala inermis in orchards, Yakima, Wash., 1924 and 1925*

| Date eggs examined | Total eggs examined | Condition of eggs | | | | | | Proportion of viable eggs hatched [1] |
|---|---|---|---|---|---|---|---|---|
| | | Alive | | Hatched | | Dead | | |
| 1924 | *Number* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Percent* |
| Apr. 18 | 645 | 601 | 93.18 | 30 | 4.65 | 14 | 2.17 | 4.75 |
| Apr. 24 | 462 | 400 | 86.58 | 35 | 7.58 | 27 | 5.84 | 8.05 |
| Apr. 25 | 478 | 396 | 82.84 | 53 | 11.09 | 29 | 6.07 | 11.80 |
| Apr. 26 | 486 | 349 | 71.81 | 100 | 20.58 | 37 | 7.61 | 22.27 |
| Apr. 28 | 507 | 279 | 55.03 | 193 | 38.07 | 35 | 6.90 | 40.90 |
| Apr. 29 | 506 | 249 | 49.21 | 189 | 37.35 | 68 | 13.44 | 43.15 |
| Apr. 30 | 474 | 278 | 58.65 | 133 | 28.06 | 63 | 13.29 | 32.36 |
| May 1 | 426 | 110 | 25.82 | 249 | 58.45 | 67 | 15.73 | 69.36 |
| May 2 | 410 | 51 | 12.44 | 268 | 65.37 | 91 | 22.19 | 84.01 |
| May 3 | 445 | 74 | 16.63 | 271 | 60.90 | 100 | 22.47 | 78.55 |
| May 5 | 830 | 177 | 21.33 | 542 | 65.30 | 111 | 13.37 | 75.38 |
| May 8 | 393 | 18 | 4.58 | 331 | 84.22 | 44 | 11.20 | 94.84 |
| May 10 | 386 | 16 | 4.15 | 289 | 74.87 | 81 | 20.98 | 94.75 |
| May 14 | 389 | 9 | 2.31 | 300 | 77.12 | 80 | 20.57 | 97.09 |
| Total | 6,837 | 3,007 | | 2,983 | | 847 | | |

[1] Based on all eggs not dead.

TABLE 2.—*Hatching of eggs of Stictocephala inermis in orchards, Yakima, Wash., 1924 and 1925*—Continued

| Date eggs examined | Total eggs examined | Condition of eggs | | | | | | Proportion of viable eggs hatched |
|---|---|---|---|---|---|---|---|---|
| | | Alive | | Hatched | | Dead | | |
| 1925 | *Number* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Percent* |
| Apr. 9 | 640 | 575 | 89.85 | 10 | 1.56 | 55 | 8.59 | 17.09 |
| Apr. 10 | 555 | 405 | 72.97 | 85 | 15.32 | 65 | 11.71 | 17.35 |
| Apr. 13 | 620 | 360 | 58.07 | 210 | 33.87 | 50 | 8.06 | 36.84 |
| Apr. 16 | 905 | 435 | 48.07 | 405 | 44.75 | 65 | 7.18 | 48.21 |
| Apr. 17 | 689 | 321 | 46.59 | 333 | 48.33 | 35 | 5.08 | 50.92 |
| Apr. 23 [2] | 322 | 59 | 18.32 | 217 | 67.39 | 46 | 14.29 | 78.62 |
| Apr. 24 | 600 | 204 | 34.00 | 352 | 58.67 | 44 | 7.33 | 63.31 |
| May 1 | 381 | 22 | 5.77 | 306 | 80.32 | 53 | 13.91 | 93.29 |
| May 5 | 670 | 25 | 3.73 | 585 | 87.31 | 60 | 8.96 | 95.90 |
| May 10 [3] | 645 | 10 | 1.55 | 570 | 88.37 | 65 | 10.08 | 98.28 |
| Total | 6,027 | 2,416 | | 3,073 | | 538 | | |

[2] Examinations on Apr. 23 were made in 2-year-old trees, whereas others were in twigs from large trees.
[3] The live eggs remaining after about this time were so grown over with new wood that the nymphs would be unable to escape.

## FACTORS INFLUENCING THE HATCHING OF EGGS

### TIME OF DAY

Practically all hatching of eggs of *Stictocephala inermis* takes place between 7 a.m. and 2 p.m., but usually about 90 percent of it occurs between 8 a.m. and 12 m. (table 3). When the preceding night temperature has been above 50° F., hatching takes place earlier than it otherwise would. Apparently eggs do not hatch at night or in the very early morning, even when the temperature is sufficiently high.

TABLE 3.—*Summary of records of the number of eggs of Stictocephala inermis hatching each hour in the insectary, Yakima, Wash., 1923, 1924, and 1925*

| Time; hour ended | Total and proportion of eggs hatching | | | | | | For the 3 years | |
|---|---|---|---|---|---|---|---|---|
| | 1923 | | 1924 | | 1925 | | | |
| | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* |
| 7 a.m. | | | 9 | 0.6 | | | 9 | 0.1 |
| 8 a.m. | 51 | 3.8 | 261 | 17.0 | 36 | 0.9 | 348 | 5.0 |
| 9 a.m. | 325 | 24.3 | 345 | 22.5 | 688 | 16.5 | 1,358 | 19.3 |
| 10 a.m. | 646 | 48.4 | 422 | 27.6 | 930 | 22.4 | 1,998 | 28.5 |
| 11 a.m. | 177 | 13.3 | 301 | 19.7 | 1,427 | 34.3 | 1,905 | 27.1 |
| 12 m. | 100 | 7.5 | 149 | 9.7 | 751 | 18.0 | 1,000 | 14.2 |
| 1 p.m. | 36 | 2.7 | 44 | 2.9 | 243 | 5.8 | 323 | 4.6 |
| 2 p.m. | | | | | 70 | 1.7 | 70 | 1.0 |
| 3 p.m. | | | | | 14 | .4 | 14 | .2 |
| Total | 1,335 | 100.0 | 1,531 | 100.0 | 4,159 | 100.0 | 7,025 | 100.0 |

### TEMPERATURE

Few eggs hatch on days when the mean temperature is below 45° F. Since nearly all of the eggs hatch during the forenoon between the hours of 8 and 12, the temperature during that period is an important factor. The writer has determined that 50° F. is the critical temperature below which hatching of the eggs rarely occurs. Of 1,335 eggs hatching in 1923 and 4,159 in 1925, none hatched at a shade temperature below 50°. Of 1,531 hatching in 1924, a few are recorded

as having hatched at temperatures ranging from 45° to 49° on April 14 and 15, and a few others at 48° on April 23 and 24. When the minimum temperature of the preceding 24 hours was comparatively high, even though it remained just at 50° during the forenoon, considerable hatching occurred. Even when a minimum of 26° had been reached in the morning, hatching occurred during the forenoon after a few hours of 50° temperature had passed, as on April 24 and 25, 1925.

There also appears to be a critical temperature above which hatching ceases. Only five eggs have been recorded as hatching at temperatures above 75° F., and only 56 eggs out of a total of 7,025 are recorded as hatching at 70° and above.

To summarize, when the morning temperature reaches or exceeds 50° in the shade, hatching will begin and continue until about noon or until a temperature of 70° in the shade is reached, after which it will soon cease for the day.

### HUMIDITY

Increased hatching has been noted in orchards on mornings when hygrothermograph records indicated high humidity, as occurs especially following night rains or during the period when the orchards are being irrigated. The daily hatching period has been somewhat prolonged on days of excessively high humidity, especially if the temperature was correspondingly favorable. On the other hand, greatly reduced hatching has been noted on days with considerable wind, even when the most favorable temperatures prevailed.

It appears that a certain degree of humidity is necessary to permit the eggs to hatch. The moisture in the air seems to render more pliable the edges of the egg pouches, allowing the extremely delicate nymphs to break through the eggshells, push themselves past the sharp edges of the bark and beyond the surface, and to free themselves from the hatching membranes. It has often been noted that nymphs attempting to emerge late in the morning are sometimes too dried out to complete emergence and die in the attempt.

### SITUATION IN THE ORCHARD

Differences occur in various situations in the orchard in the time when hatching takes place. This means that the entire hatching period is somewhat longer in the field than is the case with single lots of material under observation in the insectary.

The earliest eggs to hatch are those in water sprouts growing from the bases of the trees. These sprouts are close to the ground, where they absorb more of the reflected heat from the soil and also from the trunk of the tree. They are also probably first affected by the earliest flow of sap, which evidently increases the moisture content of the bark, cambium, and wood.

One- and two-year old trees, whose trunks are still new enough to be suitable for egg deposition, are much like water sprouts, and the eggs in them hatch earlier than do eggs in twigs in the larger trees. Examination of twigs from a large tree on April 24, 1924, and again on the 25th showed that about 8 to 12 percent of the eggs had hatched; samples from a 2-year-old tree on April 25 showed over 53 percent of the eggs hatched, while a 1-year-old, smaller tree examined on April 24 showed over 77 percent hatched. The young trees receive the

same heat reflection from the soil as do the water sprouts, but lack the additional reflection of heat from the trunk.

Eggs in twigs on the south side of large trees hatch earlier than eggs in the twigs on the north side of the same trees (table 4). On April 24 and 25, 17 and 25 percent, respectively, of the live eggs had hatched in twigs on the south side, while at that time none had hatched in the twigs on the north side. On April 26, the day on which hatching started in the twigs on the north side, over 35 percent had hatched on the south side. After a few days more, however, there appears to be little or no difference between the two sides, the general temperature throughout the tree being apparently sufficient to hatch the eggs on the north side, while those on the south side may possibly be somewhat retarded, in certain instances at least, by excessive temperature in the sunlight on that side.

TABLE 4.—*Comparison of the rate of hatching of eggs of Stictocephala inermis in the basal twigs and the terminal twigs, Yakima, Wash., 1924*

NORTH SIDE OF TREE

| Date of examination | In basal twigs [1] | | | | | In terminal twigs [1] | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Total eggs | Live eggs | Hatched eggs | Dead eggs | Proportion of viable eggs hatched [2] | Total eggs | Live eggs | Hatched eggs | Dead eggs | Proportion of viable eggs hatched [2] |
| | *Number* | *Number* | *Number* | *Number* | *Percent* | *Number* | *Number* | *Number* | *Number* | *Percent* |
| Apr. 24 | 129 | 127 | 0 | 2 | 0 | 116 | 97 | 0 | 19 | 0 |
| Apr. 25 | 121 | 120 | 0 | 1 | 0 | 125 | 114 | 0 | 11 | 0 |
| Apr. 26 | 97 | 77 | 9 | 11 | 10.47 | 131 | 120 | 7 | 4 | 5.51 |
| Apr. 28 | 116 | 77 | 37 | 2 | 32.46 | 148 | 128 | 3 | 17 | 2.29 |
| Apr. 29 | 137 | 136 | 0 | 1 | 0 | 112 | 77 | 28 | 7 | 26.67 |
| Apr. 30 | 121 | 95 | 14 | 12 | 12.84 | 126 | 88 | 28 | 10 | 24.14 |
| May 1 | 109 | 71 | 35 | 3 | 33.02 | 100 | 13 | 59 | 28 | 81.94 |
| May 2 | 102 | 13 | 73 | 16 | 84.88 | 112 | 5 | 70 | 37 | 93.33 |
| May 3 | 122 | 17 | 68 | 37 | 80.00 | 101 | 33 | 53 | 15 | 61.63 |
| May 5 | 209 | 62 | 117 | 30 | 65.36 | 206 | 37 | 150 | 19 | 57.47 |
| May 8 | 105 | 0 | 86 | 19 | 100.00 | 95 | 6 | 80 | 9 | 93.02 |
| May 10 | 87 | 5 | 44 | 38 | 89.80 | 91 | 0 | 71 | 20 | 100.00 |
| May 14 | 101 | 2 | 87 | 12 | 97.75 | 99 | 2 | 65 | 32 | 97.01 |
| Total | 1,556 | 802 | 570 | 184 | | 1,562 | 720 | 614 | 228 | |

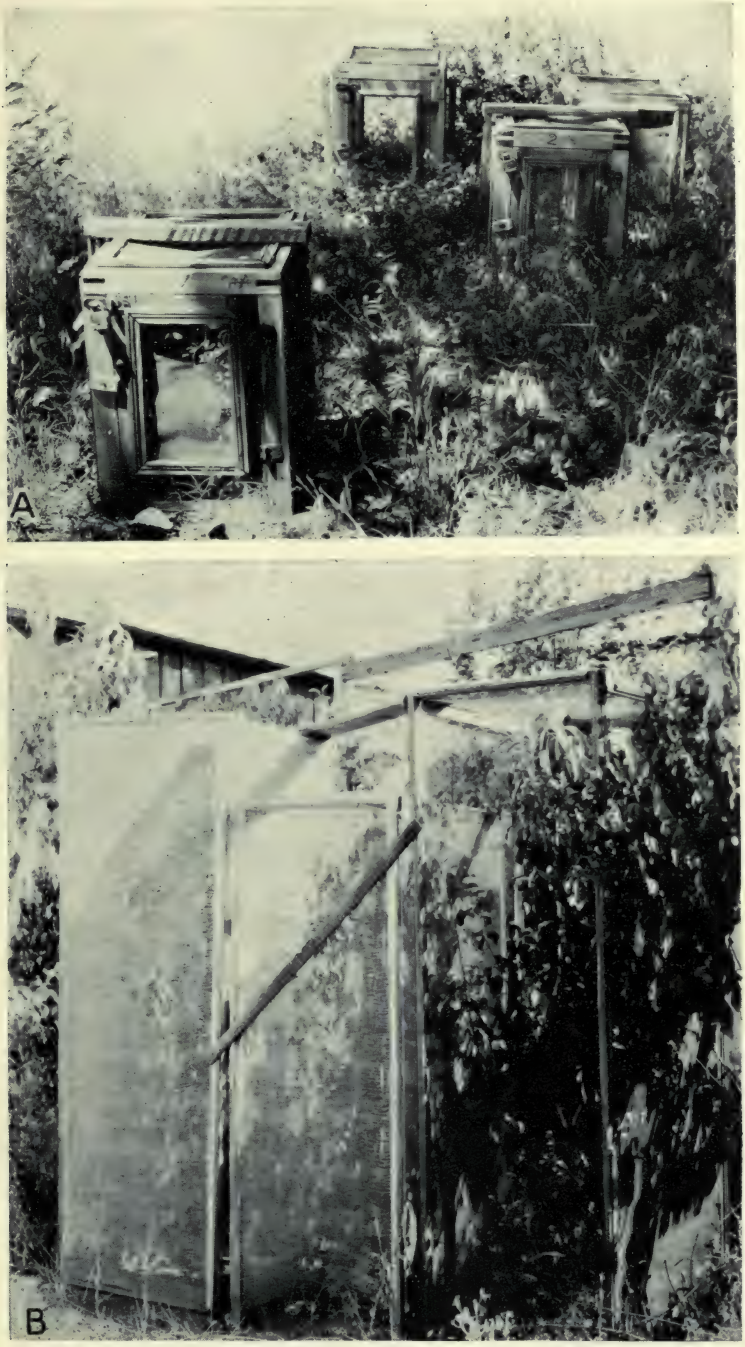
SOUTH SIDE OF TREE

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Apr. 24 | 88 | 49 | 35 | 4 | 41.67 | 129 | 127 | 0 | 2 | 0 |
| Apr. 25 | 111 | 47 | 53 | 11 | 53.00 | 121 | 115 | 0 | 6 | 0 |
| Apr. 26 | 119 | 26 | 76 | 17 | 74.51 | 139 | 126 | 8 | 5 | 5.97 |
| Apr. 28 | 131 | 16 | 107 | 8 | 86.99 | 112 | 58 | 46 | 8 | 44.23 |
| Apr. 29 | 142 | 24 | 93 | 25 | 79.49 | 115 | 12 | 68 | 35 | 85.00 |
| Apr. 30 | 122 | 42 | 51 | 29 | 54.84 | 105 | 53 | 40 | 12 | 43.01 |
| May 1 | 111 | 3 | 97 | 11 | 97.00 | 106 | 23 | 58 | 25 | 71.60 |
| May 2 | 98 | 9 | 69 | 20 | 88.46 | 98 | 24 | 56 | 18 | 70.00 |
| May 3 | 127 | 5 | 95 | 27 | 95.00 | 95 | 19 | 55 | 21 | 74.32 |
| May 5 | 207 | 49 | 118 | 40 | 70.66 | 208 | 29 | 157 | 22 | 84.41 |
| May 8 | 101 | 0 | 95 | 6 | 100.00 | 92 | 12 | 70 | 10 | 85.37 |
| May 10 | 104 | 1 | 90 | 13 | 98.90 | 104 | 10 | 84 | 10 | 89.36 |
| May 14 | 93 | 2 | 76 | 15 | 97.44 | 96 | 3 | 72 | 21 | 96.00 |
| Total | 1,554 | 273 | 1,055 | 226 | | 1,520 | 611 | 714 | 195 | |

[1] Basal twig samples were from the first few inches next to juncture with larger limbs; terminal samples were from the last few inches in newest wood.
[2] Based on all eggs not dead.

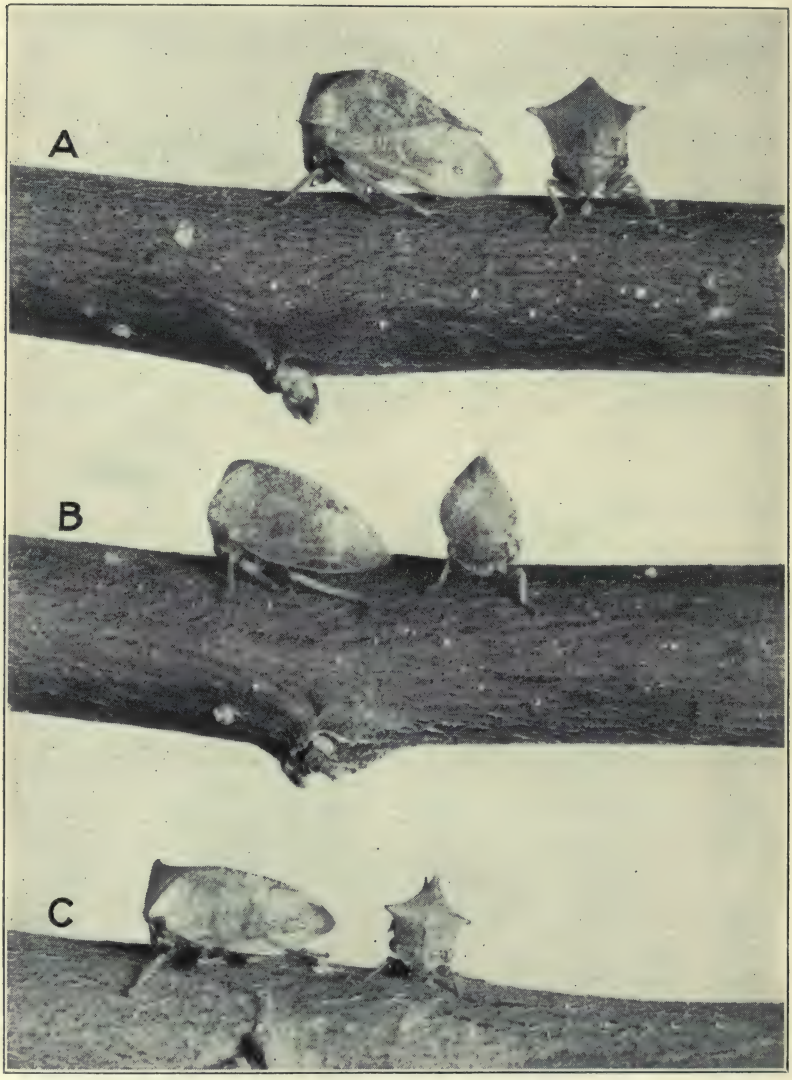
### MORTALITY OF EGGS

From time to time varying numbers of the eggs of *Stictocephala inermis* under observation have been found dead. The actual mortality in samples brought for examination has been found as high as 22.5 percent, and a number of samples, totaling 3,252 eggs, showed




TREEHOPPER REARING CAGES.

A, Small cages placed over alfalfa plants in the field. B, Larger cages enclosing young fruit trees.




A, The buffalo treehopper (*Ceresa bubalus*); B, the green clover treehopper (*Stictocephala inermis*); C the basal, or dark-colored, treehopper (*C. basalis*). All × 3.

an average of 11.7 percent dead. The highest percentage of dead eggs was found in the ends of the pouches where the eggs are excessively crowded by the growing and swelling bark and wood. A higher percentage of dead eggs was generally found at the close of the hatching period than at earlier dates. No difference in mortality appeared among eggs taken from various portions of the tree. Examinations of eggs in twigs which had been held for long periods in the insectary with their basal ends in water showed percentages of mortality only slightly in excess of those observed in the orchard at the end of the hatching period.

FIGURE 5.—Embryo of *Stictocephala inermis* removed from chorion, showing development 2 days before hatching. ×30.

A few of the living eggs are grown over by new wood tissue in early spring before hatching. In such cases the nymphs are unable to escape, and so perish.

## MECHANICS OF HATCHING

The embryonic development within the egg apparently takes place chiefly in the early spring shortly before hatching occurs. About 2 days before the eggs are ready to hatch the embryo has the appearance shown in figure 5. The hatching process is shown in figure 6 and is, briefly, as follows:

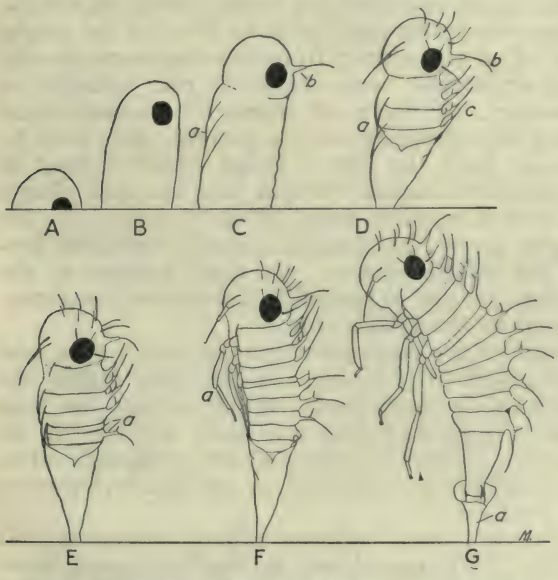



FIGURE 6.—Manner of hatching of tree-hopper nymph: *A*, First appearance of nymph above surface of bark; *B*, 2 minutes later; *C*, 2 to 5 minutes after first appearance, *a*, legs inside hatching membrane, *b*, head tuberosity; *D*, about 2 minutes after stage *C*, *a*, legs, *b*, head tuberosity, *c*, dorsal thoracic tuberosities; *E*, a few seconds after stage *D*, showing first two abdominal segments, *a*; *F*, a few seconds later, showing fifth abdominal segment and legs (*a*) pulling free from shriveled hatching membrane; *G*, a few seconds later, showing the nymph entirely free except for the anal segment, which is still attached inside the hatching membrane *a*. ×30.

The embryo nymph enclosed in the embryonic cuticula, often referred to as the "hatching membrane", breaks through the eggshell and forces itself partly out of the egg pouch. The insect then breaks through the hatching membrane and by means of pulsations within the body and a backward and forward as well as sidewise movement works itself free of the membrane. In this process the insect is aided by the tuberosities which are present on the first-instar nymph. Observations of 15 individuals in the insectary showed that the total time required for emergence from the egg ranged from 7 to 16 minutes, with an average of about 13 minutes. As soon as the young

nymph can get a foothold it pulls the remaining abdominal tuberosities loose. After freeing itself the nymph takes a few steps and then usually remains quiet for several minutes.

When considerable numbers of young have hatched, the empty, white, shriveled hatching membranes stand out conspicuously against the dark background of the twig (pl. 2, *D*) with their lower ends attached down within the egg pouch. These remain for some time, and by the end of the hatching period they give a badly infested twig a whitish, fuzzy appearance.

At times thousands of nymphs appear at approximately the same time and fall to the ground with each stir of air like miniature gusts of snow. The presence of hundreds of the whitish nymphs protruding at one time from the ragged bark of badly infested twigs (pl. 2, *E*)—sometimes two or more at the same time from a single egg pouch—is an interesting sight and was evidently responsible for Lovett's belief (*18*) that 90 percent of the eggs hatch within a few hours. Actually, of course, the percentage hatching on any one day is much less than that figure.

### HABITS OF NYMPHS

As previously indicated, the nymphs normally feed on certain herbaceous plants; in the Northwest they are found chiefly on alfalfa. The foliage of fruit trees is evidently unsuitable as food for the young nymphs, for practically all of them drop from the tree very shortly after hatching, and the writer has been unable to rear nymphs on apple foliage in the insectary. If there are strong air currents when the nymphs are hatching and dropping to the ground, they may be blown some little distance from the tree. Those which happen to reach suitable plants establish themselves and feed on such plants until becoming adults, which requires from 50 to 90 days. In the earlier stages the nymphs prefer the shaded, humid conditions prevailing at the base of the alfalfa crowns. As they develop to the fourth and fifth stages they are not so partial in this respect, and may be found several inches up on the alfalfa stems.

Feeding nymphs remain at the same place for hours at a time and do not appear to move about very much. In the later stages the nymphs are always found with their heads turned toward the base of the stems. It has been suggested that this habit is probably for the purpose of obtaining a protective resemblance, although when the insect is feeding upon alfalfa it is difficult to see that any protection is afforded by this position.

The feeding of the nymphs causes moderate injury, similar to that shown in plate 2, *C*. In alfalfa in orchards in the Northwest, however, this has not been found extensive enough to be of serious importance.

### MOLTING

The nymphs pass through five instars before reaching maturity. The molts are very much alike and are about as follows: The nymph fastens itself with its feet to the plant upon which it has been feeding and remains quiet for a number of hours. The outer integument loosens at a number of places over the body and separates from the new skin formed beneath. The old integument breaks at the back of the head and then splits along the median dorsal line, as well as over the mouth parts. The legs, after being pulled free, are waved

about until they catch hold of the leaf or stem, when they assist in pulling the tip of the abdomen free from the integument. Two nymphs were timed for the length of the molting process. One required 15 and the other 17 minutes. After freeing themselves they remained quiet for 23 and 45 minutes, respectively. The old integument is left attached to the undersides of leaves of alfalfa or sweetclover until brushed or knocked off.

### NYMPHAL DEVELOPMENT

Detailed observations as to the duration of the nymphal instars were made in 1924. The insects were reared in lantern-globe cages on thrifty alfalfa plants, supplemented with freshly cut alfalfa stems and leaves taken from as near the base of alfalfa plants as possible.

The record of the lengths of the nymphal instars of *Stictocephala inermis*, as observed in rearing 57 individuals in the insectary in 1924, are given in summary form in table 5.

TABLE 5.—*Length of the nymphal instars of 57 individuals of Stictocephala inermis hatched at daily intervals from Apr. 12 to May 12, 1924, Yakima, Wash.*

| Item | First instar | Second instar | Third instar | Fourth instar | Fifth instar | Total nymphal period |
|---|---|---|---|---|---|---|
| | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* |
| **EGGS HATCHED FROM APR. 12 TO 20** | | | | | | |
| Maximum | 27 | 12 | 10 | 17 | 31 | 91 |
| Minimum | 21 | 7 | 8 | 13 | 22 | 75 |
| Average | 23.3 | 9.1 | 8.9 | 14.6 | 26.1 | 82.0 |
| **EGGS HATCHED FROM APR. 21 TO 30** | | | | | | |
| Maximum | 22 | 10 | 10 | 19 | 29 | 77 |
| Minimum | 12 | 7 | 7 | 10 | 22 | 65 |
| Average | 16.7 | 8.0 | 8.3 | 12.9 | 24.6 | 70.5 |
| **EGGS HATCHED FROM MAY 1 TO 12** | | | | | | |
| Maximum | 15 | 9 | 9 | 12 | 24 | 62 |
| Minimum | 7 | 7 | 7 | 7 | 15 | 50 |
| Average | 10.8 | 7.6 | 8.0 | 9.9 | 19.0 | 55.2 |
| Maximum for all | 27 | 12 | 10 | 19 | 31 | 91 |
| Minimum for all | 7 | 7 | 7 | 7 | 15 | 50 |
| Average for all | 16.4 | 8.2 | 8.4 | 12.3 | 22.9 | 68.1 |

As will be noted in table 5, the earliest-hatched nymphs require a much longer time to reach maturity than late-hatched nymphs. In this table the hatching records obtained for 1924 are divided arbitrarily into three groups, according to the period in which they hatched. There is a marked tendency for the late-hatched nymphs to catch up in their development with those which hatched earlier in the season. The nymphs in this series of observations hatched over a period of 31 days from April 12, but all became mature between June 26 and July 13. Many of the latest to hatch were among the earliest to reach maturity, the last one to reach maturity having emerged from the egg April 13, whereas the first one to mature was hatched on May 7.

In 1924, to determine the difference between sunlight and shade as factors in development, newly hatched nymphs were caged on an

alfalfa plant growing in the shade, where no direct sunlight penetrated at any time, and others were caged on another alfalfa plant out in the open yard, where they received as much sunlight as was possible. On July 5 there were 9 adults in the cage in the sunlight, whereas none appeared in the shaded cage until July 16, when 12 adults emerged, all of which were males. Apparently it required at least 11 days longer for development in the shaded cage than in the one in the sunlight. Whether the shade had anything to do with producing all males is not known, neither is it known whether males require a longer period for their development.

### ADULT STAGE

A technical description of the adult of *Stictocephala inermis* is given on page 6. It is readily distinguished from its close associate *Ceresa bubalus* (pl. 4, *A*), the true buffalo tree hopper, by the rounded humeral angles and the absence of humeral horns (plate 4, *B*). *S. inermis* is intermediate in size between *C. bubalus* and *C. basalis*. It is readily distinguished from *basalis*, being greenish throughout, whereas *basalis* is dark on the under side of the body and usually has dark markings on the legs.

Records of the length of adult life of individuals confined in the insectary are shown in table 6. Under normal orchard conditions the average length of life is probably about 2 months, and adults are found in the orchard from late June until late September.

TABLE 6.—*Longevity of adults of Stictocephala inermis in confinement, Yakima, Wash., 1924*

| Number of individuals | Minimum length of life of group | Number of individuals | Minimum length of life of group | Number of individuals | Minimum length of life of group |
|---|---|---|---|---|---|
| | *Days* | | *Days* | | *Days* |
| 1 | 67 | 10 | 50 | 29 | 40 |
| 3 | 58 | 13 | 49 | 39 | 38 |
| 5 | 54 | 20 | 44 | 41 | 37 |

### MATING

According to Funkhouser (*12*), who described the process, mating begins almost immediately after the sexes reach maturity. Mating lasted from 5 minutes to 1 hour in different species, and he observed no forms in flight during mating.

In spite of repeated observations at all hours of day and night, the writer has never observed the mating process.

### OVIPOSITION

There seems to be a preoviposition period of about 25 days. Few eggs are ever found before the middle of July, and few seem to be laid after the first of September. There is therefore an egg-laying period of possibly 60 days, and a period of about 35 or 40 days during which most of the eggs are deposited.

Oviposition occurs chiefly between the hours of 10 a.m. and 5:30 p.m., though a few eggs may be deposited later during the long,

warm, sunny evenings of August. Numerous observations failed to indicate any ovipositions earlier than 10 a.m. Funkhouser (*12*), at Ithaca, N.Y., reported most oviposition as taking place during the afternoon, and this is probably true of *S. inermis* and allied species in the Yakima Valley. Wildermuth (*30*) states that *S. festina* deposits its eggs at night. This may be on account of the higher temperature prevailing throughout most of the regions where *festina* is known to occur.

The eggs are laid in groups of 1 to 11 in pouches in the bark and wood (pl. 2, *A* and *B*). They are placed chiefly in the youngest of the previous season's wood, although a few may be laid in the most mature of the current season's growth.

On large trees, more eggs are deposited on the south than on the north side. On twigs extending in a more or less horizontal direction, nearly all eggs are deposited on the upper sides. Young trees and sprouts standing more or less vertically have more eggs on the south side. In young trees, most of the eggs are deposited within 2 feet of the ground. In older trees, low-hanging twigs drooping into the alfalfa are especially favorable places for deposition. Very few eggs are found more than 6 or 7 feet above the ground, although sometimes an occasional egg pouch is found well up in the large trees.

The eggs are inserted through the bark and into the outer wood (fig. 7, *F*, *G*, *H*, and *I;* pl. 2, *A* and *B*), the inner ends extending slightly into the outer surface of the wood, their outer ends at or slightly past the surface of the inner scar; so the tips of the eggs are often visible when the loose bark flap is lifted slightly, or is removed by the elements, as often happens after several months of exposure. The exposure of egg tips is of importance in the matter of control of the insect. In badly infested twigs the egg pouches or scars are very numerous and often cut into each other, in which case some of the eggs exposed by the later cuts are killed.

### MANNER OF DEPOSITION OF EGGS

In making the slit for the eggs, the female raises her body as high as possible, unsheathes her ovipositor with its sawlike posterior edge, and slowly and methodically pushes it perpendicularly into the bark. In this perpendicular thrust the ovipositor often bends a number of times during a single insertion, owing, no doubt, to the resistance of the bark and wood. By slow up-and-down sawing movements the ovipositor is gradually worked backward until it is about in line with the body, when it is withdrawn. After this slit has been made a couple of supplementary slits are made at the side of the main incision. These are usually not so deep as the main slit and run in different directions from the original (fig. 7, *I*).

After making the supplementary slits the female again inserts her ovipositor into the egg slit from which it was last withdrawn, resumes the initial position, and slowly deposits an egg. After about 45 seconds, or less, the ovipositor is partly withdrawn and reinserted in advance of the egg just laid. In reinserting the ovipositor the tip is thrust forward of perpendicular at a considerable angle. The time required for the whole operation of inserting each egg ranges from 35 to 70 seconds, but usually averages between 45 and 60 seconds. Sometimes it is necessary for the ovipositor to be withdrawn and

reinserted a number of times before deposition is accomplished. It requires the longest time to deposit the eggs at the ends of the slits, and considerable manipulation is often necessary to accomplish this. When the full number of eggs for the pouch has been deposited the

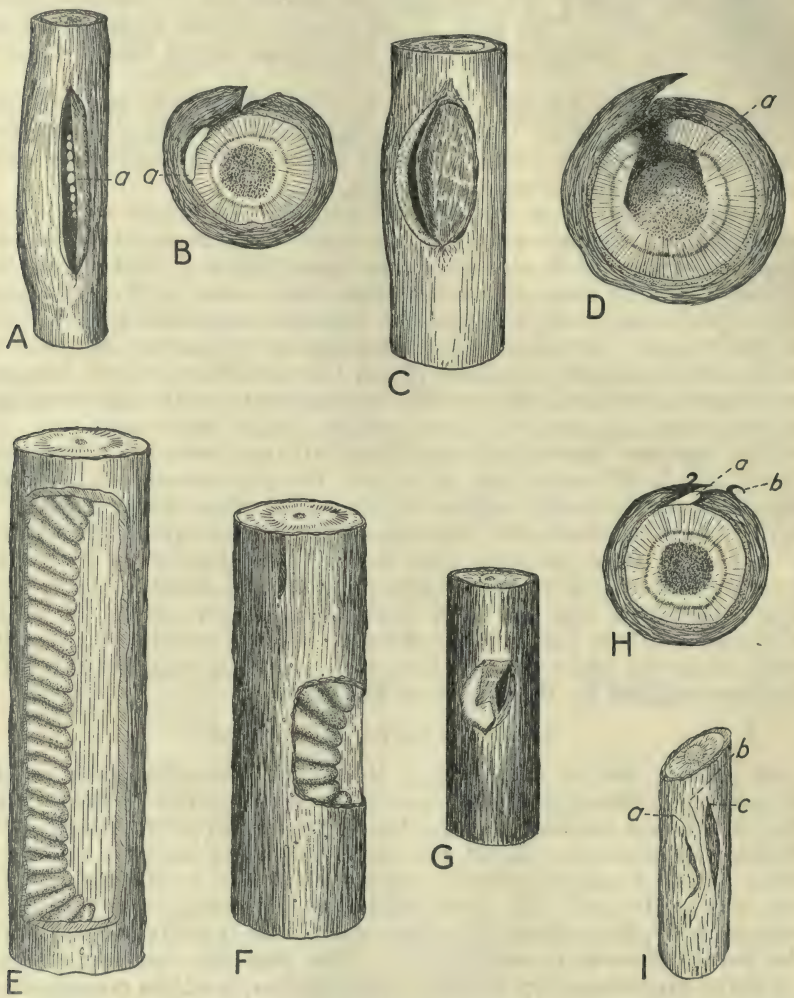



FIGURE 7.—Oviposition lesions of *Stictocephala inermis* and *Ceresa basalis*. *C. basalis: A*, New oviposition wound, showing tips of eggs (*a*), × 3; *B*, transverse section through a new wound, showing eggs (*a*) deeply inserted between the bark and the wood, × 5; *C*, 1-year-old oviposition wound, × 2; *D*, transverse section through an oviposition wound, showing decay (*a*) penetrating through to the heartwood, × 7; *E*, section of twig with bark removed, showing the position of *basalis* eggs in the egg pouch, × 4. *S. inermis: F*, Apple twig with bark removed to show position of *inermis* eggs in the egg pouch, × 4; *G*, oviposition scar of *inermis*, × 2; *H*, transverse section through oviposition pouch in an apple twig, showing (*a*) the shallow position of the egg, and (*b*) the curled edges of the outer bark characteristic of this species, × 5; *I*, oviposition scar (*c*) and supplementary incisions (*a* and *b*) which cause the curling of the outer bark, × 4.

female withdraws her ovipositor, resheathes it, walks away, and rests.

The supplementary slits kill the outer bark on either side of the egg slit, causing the free edges to curl away from the cut (pl. 1), and resulting in the roughened, shaggy appearance characteristic of the

bark of infested twigs. Although the purpose of the supplementary slits is unknown, the killing of the outer bark around the egg pouch prevents the eggs from being grown over by the bark and wood, which might prevent them from hatching the following year. *Ceresa bubalus* cuts two longitudinal slits, between which the wood does not grow, thus protecting her eggs. *C. basalis* cuts a deep, long, longitudinal slit, which usually opens and widens instead of growing over.

The number of eggs in each slit or pouch ranges from 1 to 11 (table 7). The average number of eggs in 3,765 pouches, dissected under the microscope in 1923, 1924, and 1925, was 5.6.

TABLE 7.—*Number of eggs per pouch laid by Stictocephala inermis, Yakima, Wash., 1923, 1924, 1925*

| Year | Pouches containing the number of eggs indicated | | | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | |
| | Number | Number | Number | Number | Number | Number | Number | Number | Number | Number | Number | Number |
| 1923 | 6 | 19 | 69 | 203 | 656 | 727 | 366 | 114 | 25 | 10 | 1 | 2,196 |
| 1924 | 3 | 26 | 70 | 185 | 318 | 262 | 118 | 28 | 12 | 1 | 0 | 1,023 |
| 1925 | 0 | 10 | 25 | 55 | 150 | 185 | 85 | 30 | 6 | 0 | 0 | 546 |
| Total | 9 | 55 | 164 | 443 | 1,124 | 1,174 | 569 | 172 | 43 | 11 | 1 | 3,765 |

The number of egg pouches made by the *inermis* female was not determined because of difficulty in approximating normal environmental conditions. In rearing cages placed over young fruit trees into which were introduced large numbers of females, the highest average number of egg pouches in any one cage was 8.6 per female, with an average of 47 eggs for each female. Hodgkiss (*17*) reports one female as depositing 252 eggs in 59 scars and another individual as placing 212 eggs in 39 scars. It is probable that not less than 200 eggs would represent a fair average per individual for conditions in the Yakima Valley. Certainly few females are seen ovipositing compared with the thousands of eggs deposited.

## CERESA BASALIS WALK.

### HISTORY AND DISTRIBUTION

Another membracid more or less commonly associated with *Stictocephala inermis* is *Ceresa basalis*. This species is at present less numerous than *S. inermis*, and the evidences of its presence are less abundant. In some respects, however, it is more injurious on account of the nature of its injury, which is more pronounced than that of any of the other species with which the writer is acquainted.

The first reference to *C. basalis* as occurring in the Pacific Northwest was by Wilson (*31*) in Oregon in 1915. Downes (*5*) listed it as occurring in British Columbia in 1917 and 1918 and reported it as the commonest membracid found there. The writer (*32, 33*) discussed it as common in Washington and elsewhere in the Pacific Northwest in 1924 and later. Essig (*6*) mentions it as occurring also in California, Utah, and New Mexico, and in eastern States. Funkhouser (*13*) reports it from the following States and Canadian Provinces: New Hampshire, Massachusetts, Connecticut, New York,

New Jersey, Pennsylvania, Kentucky, Ohio, Indiana, Illinois, Kansas, Colorado, Utah, Idaho, New Mexico, California, Oregon, Washington, Nova Scotia, Quebec, Ontario, Manitoba, Saskatchewan, and British Columbia. It is therefore probably distributed throughout the southern Provinces of Canada and throughout the United States except in the extreme Southeastern States.

## SYNONYMY AND COMMON NAME

This species was first described by Walker (*29, p. 527*), in 1851, from specimens from Nova Scotia. In 1889 Provancher (*22, p. 235*) redescribed it as *brevicornis* and also as *semicrema*. Osborn, in 1893, as reported by Nutting (*20, p. 290*), designated it *melanogaster*. Goding (*14, p. 406*), in 1894, classified it as *basalis* and also designated it as a new species, *turbida*. Buckton, in 1903 (*4, p. 174*), described it as *semibrunnea* and placed it in the genus *Stictocephala* of Stål. After Van Duzee's discussion of it in 1908 (*28, p. 114*), under its original designation of *Ceresa basalis*, all subsequent references have retained this name.

The most important references to this species are by Funkhouser (*13*), in 1927, and by the writer (*32*) in 1924 and (*33*) in 1930.

This species has been called by the common names "western tree hopper" by the writer (*32, p. 97*); the "basal tree hopper," by Essig (*6, p. 204*); and the "dark-colored tree hopper", by the writer (*33, p. 2*).

The more important synonymy is as follows:

*Ceresa basalis* Walker, 1851 (*29, p. 527*)
*Ceresa brevicornis* Provancher, 1889 (*22, p. 235*)
*Ceresa semicrema* Provancher, 1889 (*22, p. 235*)
*Ceresa melanogaster* Osborn, 1893 (*20, p. 290*)
*Ceresa turbida* Goding, 1894 (*14, p. 406*)
*Stictocephala semibrunnea* Buckton, 1903 (*4, p. 174*)
*Ceresa basalis* Van Duzee, 1908 (*28, p. 114*)

## CHARACTER AND IMPORTANCE OF INJURY

The oviposition scars of *C. basalis* consist of long, deeply cut, longitudinal slits, which penetrate through the bark and into the wood (fig. 7, *A, C;* pl. 5, *B*). Although the scars appear slight when first made, the edges of the slit separate as the twig grows until a clear-cut and very pronounced incision results. The widening of the scar often continues through succeeding seasons, until the wood underneath the wound is exposed (pl. 5, *A, a*). These wounds often become infested by the woolly apple aphid, *Eriosoma lanigerum* Hausm., which interferes seriously with their healing. In some instances decays enter through these wounds and penetrate into the wood (fig. 7, *D*).

While less numerous than the scars made by *S. inermis*, the wounds caused by this membracid are much more conspicuous and more readily noticed. The wounds are deeper, and the actual damage to the tree or twig is much greater. These wounds often cause the death of the terminal growth of the twigs (pl. 5, *C* and *D*). Usually a half dozen scars in the terminal 6 inches of the twig are sufficient to kill it.

As in the case of injury by *Stictocephala inermis*, nursery trees and young orchard trees are the most seriously affected. Egg scars of

TREEHOPPER INJURIES TO TWIGS.

A, Old oviposition scars of *Ceresa basalis* and *C. bubalus; a*, wounds of *basalis* widened to such an extent as to expose the wood underneath; *b*, old oviposition scars of *C. bubalus*. B, Oviposition scars of *C. basalis* in *a*, pear, *b*, willow, *c*, apple, *d*, locust, and *e*, prune. × ⅔. C, Two-year-old apple tree showing serious infestation by both *Stictocephala inermis* and *C. basalis*, the death of the twigs beyond the leaf clusters was caused by the scars of *C. basalis*. D, Terminal apple twig killed by *C. basalis;* the twig beyond the leaf cluster is dead as oviposition slits were made in the twig to within 1 inch of the terminal bud.

A, Apple twig showing scars of *Ceresa bubalus* at *a*, of *C. basalis* at *b* and *d*, and of *Stictocephala inermis* at *c*; *a* and *d* show also the presence of the woolly apple aphid; the twig at the right is the terminal of the one on the left and shows less infestation. B, Oviposition scars of *C. bubalus* on elm. C, Two groups of *C. basalis* eggs with bark and wood removed showing the curved line made by the ends of the eggs. The group at the left was taken during the hatching period and shows unhatched eggs at the ends. × 3.

this species have been found in apple, peach, pear, willow, locust, and prune trees. Fortunately, *C. basalis* is comparatively scarce at the present time, or very serious injury would result to fruit trees in the Northwest.

## FOOD PLANTS

The only known food plants of this species in the Pacific Northwest are alfalfa and sweetclover. It has been reported by Downes (*5*) on goldenrod, and other herbaceous plants, but whether for feeding or oviposition is not stated. Funkhouser (*12*) reports it on rose, probably being there for oviposition purposes only.

## DESCRIPTION OF INSTARS

The egg and the five nymphal instars of *Ceresa basalis* are very similar to those of *Stictocephala inermis*, already described. The main apparent difference between the nymphal instars of the two species is in the somewhat darker spots on the integument of *basalis*. Measurements of the several instars (fig. 8) are as follows: First instar 1.65 to 1.85 mm, second instar 2.35 to 2.75 mm, third instar 3.25 to 4.0 mm, fourth instar 5.0 to 5.75 mm, fifth instar 6.0 to 6.75 mm.

Detailed examinations of the tuberosities of the five instars of *C. basalis* show the same number of tuberosity spines in the first instar (fig. 9, *A*) as in *S. inermis*, 7 to 10 tuberosity spines in the second instar (fig. 9, *B*), 11 to 20 or more in the third instar (fig. 10), 13 to 26 or more in the fourth instar (fig. 11), and 25 to 33 or more in the fifth instar (fig. 12). The tuberosities are shorter, heavier, and comparatively broader at the base than those of *S. inermis* (fig. 13, *A* and *B*). There are more subspines on the tuberosities than with *S. inermis*, and these are shorter and more slender. In the second instar short subspines appear on the base of the tuberosities. These become more numerous in succeeding instars until there are at least 7 or 8 of them on each tuberosity in the fourth and fifth instars.

## DESCRIPTION OF ADULT

Head broader than long, roughly punctured, not pubescent; eyes prominent, extending as far laterally as humeral angles; ocelli distinct, reddish; pronotum deeply punctate, very hairy, humeral angles prominent, superhumeral horns short, obtuse, horizontal; dorsal crest convex; posterior process slender, dark, slightly decurved at tip. Under surface of body black below and segments dark bordered. Under parts of head and large part of femora black or dark brown. Length 7.5 mm. (See pl. 4, *C*; figs. 8, *G*, *H*, and 14, *D*.)

## LIFE HISTORY AND HABITS

The observations on the life history and habits of this species were made, for the most part, coincident with those on *Stictocephala inermis* and other species, but certain experiments were conducted on this species alone. Much of the discussion for *S. inermis* serves equally well for *Ceresa basalis*.

### HIBERNATION AND HATCHING

The eggs of *C. basalis* (fig. 7, *B*, *E*) are deposited in August and September, and the egg is the only stage in which the insect survives the winter. Although the earliest eggs of *Stictocephala inermis* are deposited in the middle or latter part of July, it is probable that no *basalis* eggs are laid until the 1st of August.

As the eggs are deposited much deeper in the wood than are those of *S. inermis* (fig. 7, *B*, *a*, compare with *H*, *a*), they seem to require more accumulated temperature to incubate them, and consequently they do not begin hatching until 3 weeks or more after those of *S. inermis*, or at about the time the last of these have hatched.

Records of the hatching of eggs brought into the insectary in 1924 and in 1925 are given in table 8. Observations made in the field as

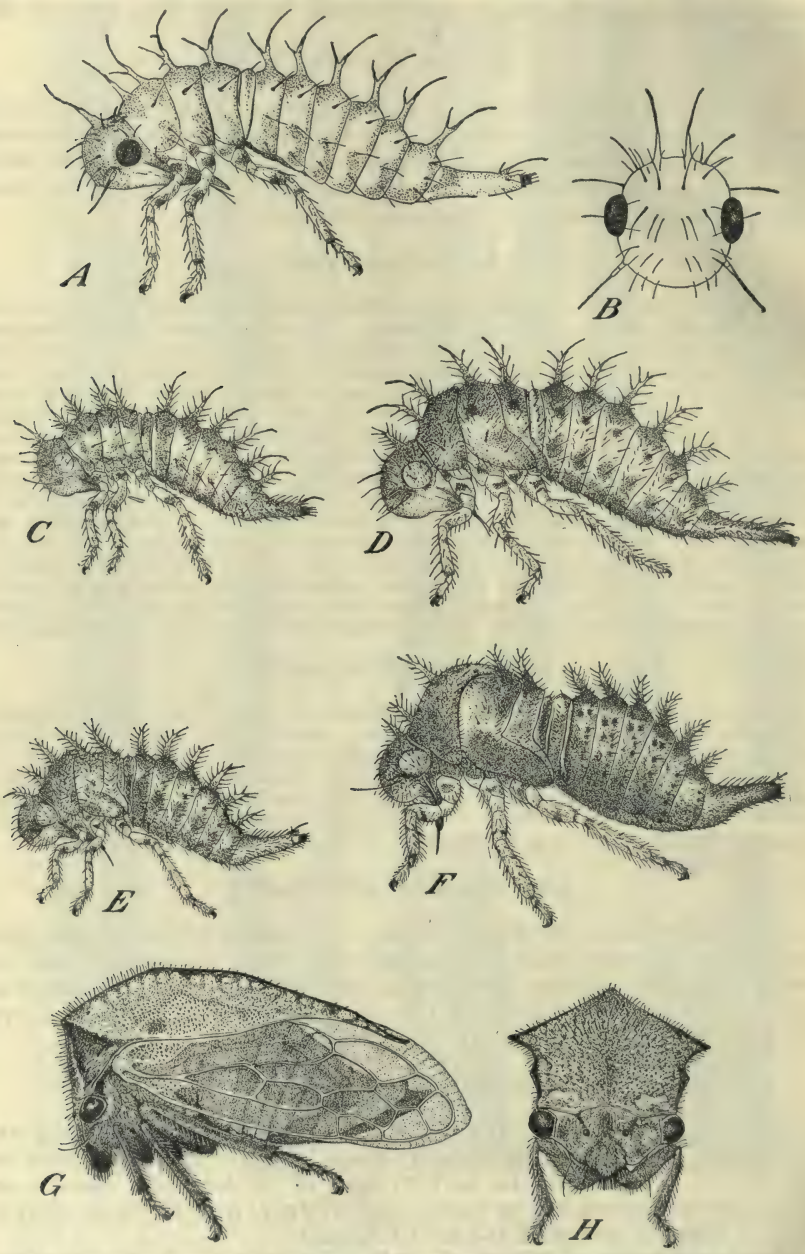



FIGURE 8.—Successive stages in the development of *Ceresa basalis*: *A*, First instar nymph, side view, ×35; *B*, first instar, front view of head, ×45; *C*, second instar, ×15; *D*, third instar, ×15; *E*, fourth instar, ×7; *F*, fifth instar, ×8; *G*, adult, side view, ×7; *H*, adult, front view, ×7.

to the progress of hatching in 1924 are shown in table 9. In 1924 and 1925 the first hatching in the orchard was observed on April 30, and the last on May 13 in 1924 and May 17 in 1925.

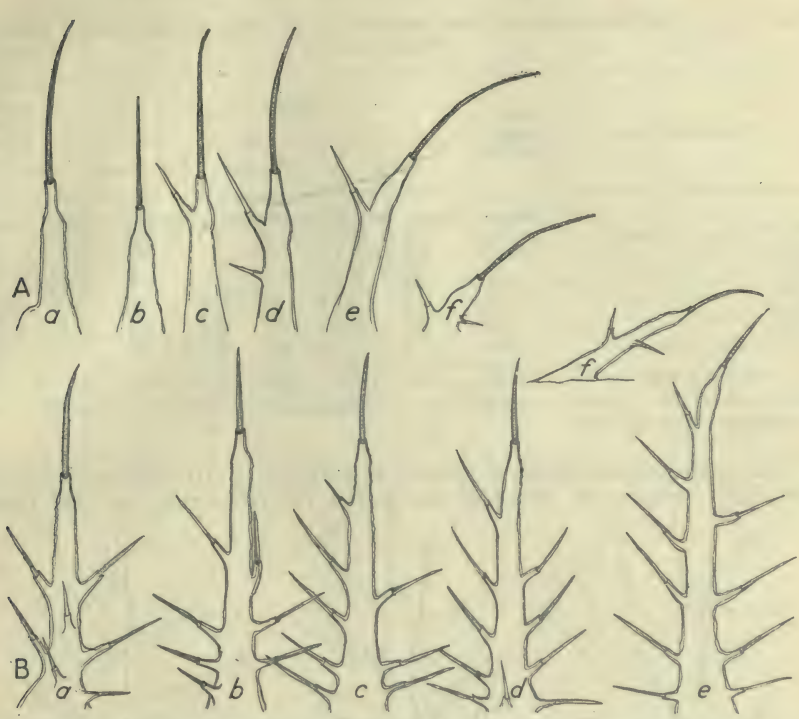



FIGURE 9.—Dorsal tuberosities on nymphs of *Ceresa basalis:* *A*, First instar; *a*, head tuberosity; *b*, first prothoracic tuberosity; *c*, second prothoracic; *d*, mesothoracic; *e*, abdominal; *f*, anal. *B*, Second instar (the same designations).

TABLE 8.—*Summary of the hatching of eggs of Ceresa basalis in the insectary, and the relation to temperature, 1924 and 1925, Yakima, Wash.*

| Date | Eggs hatched | | Temperature | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | 1924 | | | 1925 | | |
| | 1924 | 1925 | Minimum | Maximum | Mean | Minimum | Maximum | Mean |
| | *Number* | *Number* | *° F.* | *° F.* | *° F.* | *° F.* | *° F.* | *° F.* |
| May 1 | 0 | 0 | 39 | 76 | 58 | 45 | 71 | 55 |
| May 2 | 0 | 0 | 47 | 78 | 60 | 41 | 68 | 53 |
| May 3 | 0 | 0 | 39 | 66 | 53 | 39 | 68 | 54 |
| May 4 | [1] 1 | 0 | 33 | 58 | 45 | 47 | 77 | 61 |
| May 5 | 21 | 14 | 35 | 63 | 51 | 50 | 82 | 65 |
| May 6 | 72 | [1] 5 | 40 | 74 | 56 | 52 | 85 | 68 |
| May 7 | 73 | 0 | 39 | 72 | 58 | 44 | 48 | 46 |
| May 8 | 140 | 0 | 47 | 80 | 64 | 43 | 56 | 48 |
| May 9 | 141 | 0 | 54 | 87 | 71 | 36 | 68 | 54 |
| May 10 | 123 | 0 | 55 | 90 | 73 | 50 | 73 | 61 |
| May 11 | 93 | 37 | 57 | 92 | 74 | 48 | 74 | 60 |
| May 12 | 7 | 40 | 60 | 93 | 78 | 49 | 75 | 62 |
| May 13 | 0 | 40 | 68 | 92 | 77 | 53 | 78 | 65 |
| May 14 | | 28 | | | | 58 | 84 | 70 |
| May 15 | | 11 | | | | 54 | 84 | 69 |
| May 16 | | 5 | | | | 63 | 82 | 72 |
| May 17 | | 2 | | | | 58 | 79 | 68 |
| May 18 | | 2 | | | | 58 | 68 | 63 |
| Total | 671 | 190 | | | | | | |

[1] Last recorded hatching of *S. inermis* in the insectary.

TABLE 9.—*Hatching of eggs of Ceresa basalis in apple twigs in an orchard, Yakima, Wash., 1924*

| Date of observation | Total eggs observed | Condition of eggs | | | | | | Proportion of viable eggs hatched[1] |
|---|---|---|---|---|---|---|---|---|
| | | Alive | | Hatched | | Dead | | |
| | *Number* | *Number* | *Percent* | *Number* | *Percent* | *Number* | *Percent* | *Percent* |
| Mar. 22 | 210 | 178 | 84.8 | 0 | 0 | 32 | 15.2 | 0 |
| Apr. 1 | 1,105 | 958 | 86.7 | 0 | 0 | 147 | 13.3 | 0 |
| Apr. 8 | 36 | 27 | 75.0 | 0 | 0 | 9 | 25.0 | 0 |
| May 1 | 632 | 485 | 76.7 | 0 | 0 | 147 | 23.3 | 0 |
| May 3 | 198 | 147 | 74.2 | 33 | 16.7 | 18 | 9.1 | 18.3 |
| May 8 | 1,167 | 602 | 51.6 | 212 | 18.2 | 353 | 30.2 | 26.0 |
| May 9 | 708 | 184 | 26.0 | 174 | 24.6 | 350 | 49.4 | 48.6 |
| May 14 | 1,625 | 5 | .3 | 463 | 28.5 | 1,157 | 71.2 | 98.9 |
| Total or average | 5,681 | 2,586 | 45.5 | 882 | 15.5 | 2,213 | 39.0 | 61.0 |

[1] Based on all eggs not dead.

The hatching period for *C. basalis* is very short (10 days or 2 weeks), probably because of the high temperatures occurring at that time.

FIGURE 10.—Dorsal tuberosities on third-instar nymphs of *Ceresa basalis*: *A*, Head tuberosity; *B*, first prothoracic tuberosity; *C*, second prothoracic; *D*, mesothoracic; *E*, metathoracic; *F*, abdominal; *G*, anal.

The hatching process of *basalis* eggs is as described for the eggs of *inermis*, and the weather conditions conducive to the hatching of one species are apparently favorable for the other, although *basalis* requires a higher degree of temperature or a greater accumulation of day degrees in the spring to start hatching.

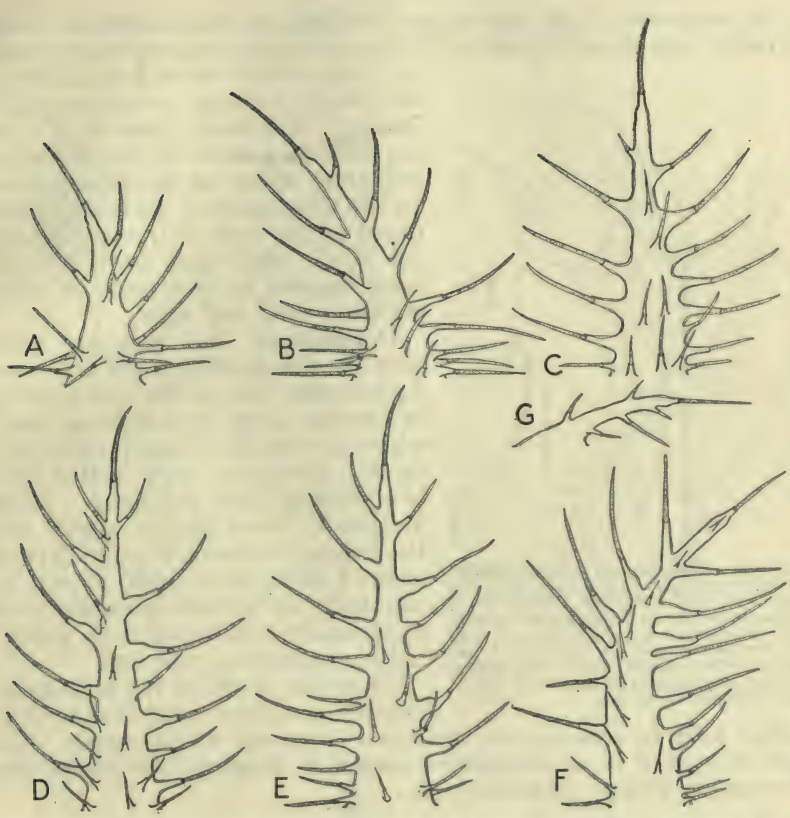



FIGURE 11.—Dorsal tuberosities on fourth-instar nymphs of *Ceresa basalis*. (Designations as in fig. 10.)

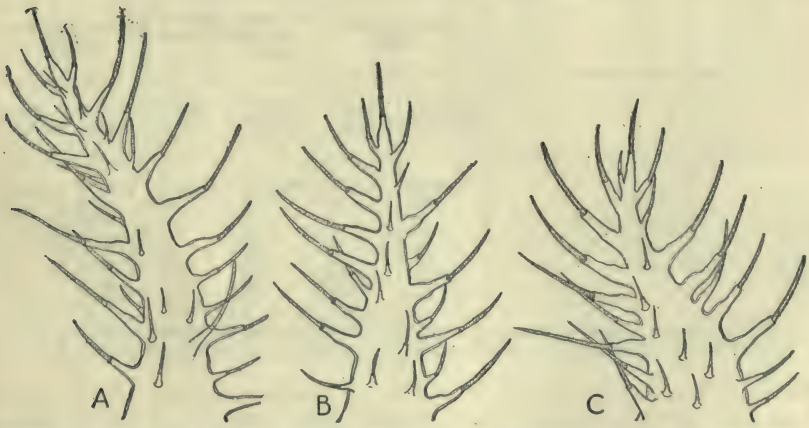



FIGURE 12.—Dorsal tuberosities on fifth-instar nymphs of *Ceresa basalis*: *A*, Mesothoracic tuberosity; *B*, metathoracic tuberosity; *C*, abdominal tuberosity.

### MORTALITY OF EGGS

The extremely high mortality of the eggs of this species is worthy of note. As shown in table 10 the mortality is greatest in terminal twigs which have been killed by the presence of egg punctures of this species. Evidently, few of the eggs are able to withstand the shrinking, withering effect of the drying wood. In live wood most of the dead eggs are found at the ends of the egg pouches (pl. 6, *C*), and these have probably been injured by the pressure of the growing wood and bark.

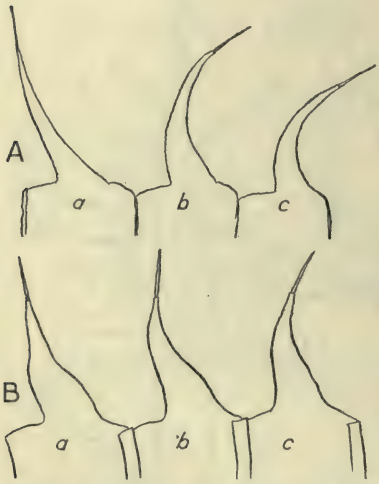



FIGURE 13.—Diagrammatic representation of dorsal tuberosities: *A*, *a*, *b*, and *c*, first, second, and third abdominal tuberosities of *Stictocephala inermis* (long, slender, spinate, curving more or less strongly caudad); *B*, *a*, *b*, *c*, first, second, and third abdominal tuberosities of *Ceresa basalis* (broad, stout, leaning forward, and not curving so strongly caudad as in *Stictocephala inermis*).

Occasionally the eggs are sealed over by the growing bark and wood. An extreme case of this was observed in sprouts taken from a prune tree in which the eggs in 37 egg pouches were mostly alive but were sealed in by overgrowing bark and wood. Examination of these eggs a month after the close of the normal hatching period showed them to be fresh, plump, and seemingly alive, with normally developed embryos showing eyes, abdominal segmentation, and legs.

Since the death of the terminals is usually the direct result of oviposition farther back by this species, the insect is its own worst enemy. This high mortality is an important factor in keeping this insect from becoming a serious economic pest.

TABLE 10.—*Comparison of the mortality of eggs of Ceresa basalis in live parts and dead withered terminals of the same twigs, Yakima, Wash., 1924*

| Date of observation | In live parts of twigs | | In dead, withered terminals of same twigs | | Proportion of eggs dead in— | |
|---|---|---|---|---|---|---|
| | Eggs hatched or alive | Eggs dead | Eggs hatched or alive | Eggs dead | Live twigs | Dead terminals |
| | *Number* | *Number* | *Number* | *Number* | *Percent* | *Percent* |
| Apr. 1 | 938 | 85 | 20 | 62 | 8.31 | 75.61 |
| Apr. 8 | 24 | 6 | 3 | 3 | 20.00 | 50.00 |
| May 1 | 446 | 56 | 39 | 91 | 11.16 | 70.00 |
| May 3 | 148 | 1 | 32 | 17 | .67 | 34.69 |
| May 8 | 736 | 122 | 78 | 231 | 14.22 | 74.76 |
| May 9 | 312 | 99 | 46 | 251 | 24.09 | 84.51 |
| May 14 | 433 | 201 | 35 | 956 | 31.70 | 96.47 |
| Total | 3,037 | 570 | 253 | 1,611 | | |

### HATCHING OF EGGS

As in the case of *Stictocephala inermis*, the eggs of *Ceresa basalis* hatch during the forenoon, although they have a tendency to hatch

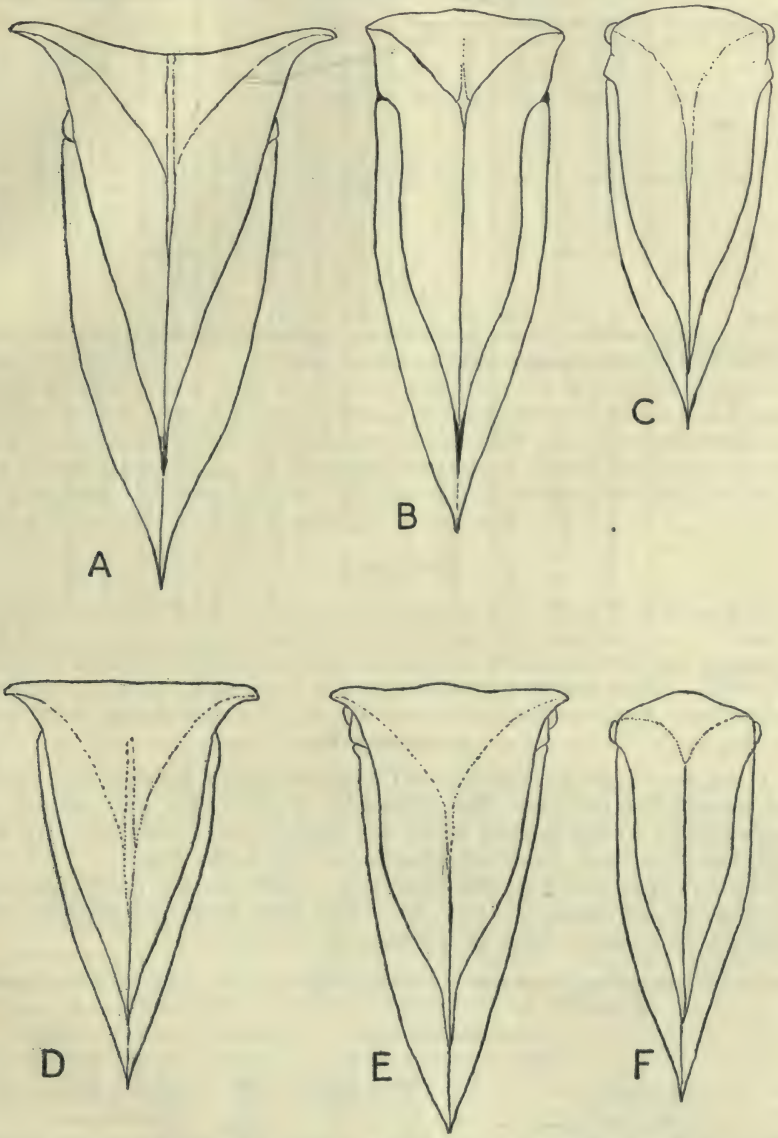



FIGURE 14.—Outline of dorsal view of six species of Membracidae: *A*, *Ceresa bubalus*; *B*, *Stictocephala inermis*; *C*, *S. pacifica* Van Duzee; *D*, *C. basalis*; *E*, *C. brevis*. Walk.; *F*, *S. wickhami* Van Duzee. ×9.

earlier in the morning than do those of *S. inermis*. Summarized records of the hourly hatching observed in the insectary in 1924 and 1925 are shown in table 11.

TABLE 11.—*Number of eggs of Ceresa basalis hatching daily and hourly in the insectary, Yakima, Wash., 1924 and 1925*

| Date | Number of eggs hatched during the hour ended at— | | | | | | | Total | Percent of total | Temperature in °F. at — | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 7 a.m. | 8 a.m. | 9 a.m. | 10 a.m. | 11 a.m. | 12 m. | 1 p.m. | | | 7 a.m. | 8 a.m. | 9 a.m. | 10 a.m. | 11 a.m. | 12 m. | 1 p.m. |
| 1924 | | | | | | | | | | | | | | | | |
| May 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0.15 | 40 | 48 | 51 | 52 | 56 | 55 | 54 |
| 5 | 0 | 0 | 0 | 0 | 17 | 4 | 0 | 21 | 3.13 | 38 | 50 | 54 | 58 | 61 | 61 | 61 |
| 6 | 0 | 0 | 0 | 1 | 38 | 22 | 11 | 72 | 10.73 | 44 | 48 | 52 | 58 | 65 | 70 | 71 |
| 7 | 0 | 0 | 8 | 37 | 18 | 10 | 0 | 73 | 10.88 | 47 | 55 | 61 | 63 | 65 | 68 | 71 |
| 8 | 0 | 50 | 57 | 31 | 0 | 0 | 0 | 138 | 20.57 | 51 | 60 | 67 | 74 | 78 | 80 | 81 |
| 9 | 2 | 101 | 32 | 6 | 2 | 0 | 0 | 143 | 21.31 | 58 | 65 | 72 | 78 | 82 | 85 | 87 |
| 10 | 0 | 97 | 21 | 5 | 0 | 0 | 0 | 123 | 18.33 | 60 | 67 | 75 | 83 | 86 | 89 | 90 |
| 11 | 0 | 80 | 13 | 0 | 0 | 0 | 0 | 93 | 13.86 | 61 | 68 | 80 | 85 | 87 | 90 | 92 |
| 12 | 1 | 5 | 1 | 0 | 0 | 0 | 0 | 7 | 1.04 | 67 | 76 | 81 | 83 | 85 | 87 | 92 |
| 13 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 69 | 74 | 81 | 84 | 87 | 88 | 90 |
| Total | 3 | 333 | 132 | 81 | 75 | 36 | 11 | 671 | | | | | | | | |
| Percentage of total | 0.44 | 49.63 | 19.67 | 12.07 | 11.18 | 5.37 | 1.64 | | | | | | | | | |
| 1925 | | | | | | | | | | | | | | | | |
| May 5 | 0 | 1 | 11 | 1 | 1 | | | 14 | 7.37 | 55 | 61 | 68 | 76 | 78 | | |
| 6 | 5 | 0 | 0 | 0 | 0 | | | 5 | 2.63 | 57 | 65 | 73 | 76 | 80 | | |
| 7 | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 45 | 45 | 46 | 46 | 46 | | |
| 8 | 0 | 0 | 0 | 0 | 0 | | | 0 | 0 | 44 | 43 | 44 | 44 | 44 | | |
| 9 | 0 | 2 | 2 | 1 | 1 | | | 6 | 3.16 | 49 | 54 | 58 | 62 | 64 | | |
| 11 | 5 | 18 | 4 | 7 | 3 | | | 37 | 19.48 | 53 | 55 | 59 | 64 | 68 | | |
| 12 | 4 | 19 | 10 | 7 | 0 | | | 40 | 21.05 | 51 | 56 | 60 | 65 | 70 | | |
| 13 | 6 | 33 | 0 | 1 | 0 | | | 40 | 21.05 | 57 | 61 | 65 | 70 | 75 | | |
| 14 | 3 | 21 | 3 | 1 | 0 | | | 28 | 14.74 | 61 | 63 | 70 | 76 | 80 | | |
| 15 | 0 | 8 | 3 | 0 | 0 | | | 11 | 5.79 | 57 | 63 | 70 | 75 | 79 | | |
| 16 | 0 | 5 | 0 | 0 | 0 | | | 5 | 2.63 | 65 | 67 | 70 | 74 | 76 | | |
| 17 | 0 | 1 | 1 | 0 | 0 | | | 2 | 1.05 | 58 | 61 | 65 | 70 | 73 | | |
| 18 | 0 | 0 | 1 | 1 | 0 | | | 2 | 1.05 | 59 | 60 | 63 | 63 | 62 | | |
| Total | 23 | 108 | 35 | 19 | 5 | | | 190 | | | | | | | | |
| Percentage of total | 12.11 | 56.84 | 18.42 | 10.00 | 2.63 | | | | | | | | | | | |

## NYMPHAL PERIOD

The newly hatched nymphs of *C. basalis* have a tendency to remain for several hours upon the underside of the twigs and do not fall immediately to the ground as do the nymphs of *S. inermis*. By midday, however, they have all disappeared from the trees.

Observations made in the insectary in 1925 on the development of 36 nymphs are shown in table 12. The total nymphal period ranged from 62 to 80 days, with an average of 70.1 days.

TABLE 12.—*Length of the nymphal instars of 36 individuals of Ceresa basalis hatched from May 11–17, inclusive, 1925, at Yakima, Wash.*

EGGS HATCHED MAY 11 AND 12

| Item | First instar | Second instar | Third instar | Fourth instar | Fifth instar | Total nymphal period |
|---|---|---|---|---|---|---|
| | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* |
| Maximum | 18 | 20 | 15 | 22 | 17 | 80 |
| Minimum | 9 | 11 | 10 | 11 | 11 | 62 |
| Average | 11.8 | 13.6 | 12.8 | 16.0 | 14.6 | 68.8 |

EGGS HATCHED MAY 13 AND 14

| | | | | | | |
|---|---|---|---|---|---|---|
| Maximum | 12 | 21 | 14 | 18 | 16 | 78 |
| Minimum | 10 | 16 | 9 | 9 | 11 | 63 |
| Average | 11.5 | 18.2 | 11.9 | 15.4 | 14.6 | 71.6 |

TABLE 12.—*Length of the nymphal instars of 36 individuals of Ceresa basalis hatched from May 11–17, inclusive, 1925, at Yakima, Wash.*—Continued

EGGS HATCHED MAY 15 AND 17

| Item | First instar | Second instar | Third instar | Fourth instar | Fifth instar | Total nymphal period |
|---|---|---|---|---|---|---|
| | *Days* | *Days* | *Days* | *Days* | *Days* | *Days* |
| Maximum | 18 | 17 | 14 | 16 | 19 | 73 |
| Minimum | 11 | 13 | 9 | 11 | 12 | 69 |
| Average | 14.8 | 15.5 | 11.3 | 13.3 | 15.7 | 70.7 |
| Maximum for all | 18 | 21 | 15 | 22 | 19 | 80 |
| Minimum for all | 9 | 11 | 9 | 9 | 11 | 62 |
| Average for all | 12.2 | 15.6 | 12.3 | 15.3 | 14.8 | 70.1 |

### ADULT STAGE

Most of the nymphs change to adults in July, the earliest definite record being July 11. By the middle of the month adults are usually out in numbers, and they have been found in the field until October 8.

The earliest record of egg deposition for *C. basalis* is one for August 13, 33 days after the first adults matured that year, so there seems to be a preoviposition period of approximately a month, as in the case of *Stictocephala inermis*. With *C. basalis*, however, oviposition continues later into the fall than with *S. inermis*.

### OVIPOSITION

Females have been observed depositing eggs from 9 a.m. to 6 p.m., and few, if any, eggs are deposited outside these hours.

As with *Stictocephala inermis*, the eggs of *Ceresa basalis* are deposited in water sprouts arising at the bases of the trees and in the twigs that hang down toward or into the alfalfa cover crop, but seldom higher in the trees than 6 or 7 feet from the ground. Eggs are also laid in nursery stock and young orchard trees.

The eggs are deposited in the upper side of twigs running more or less horizontally, but on twigs or young trees standing vertically or nearly so they may be found on any side though in greater numbers on the south side. There is often an overlapping or intermingling of oviposition scars of this species and of *Stictocephala inermis* and *Ceresa bubalus*, but the majority of *basalis* egg scars are beyond those of *inermis* and *bubalus* in newer, softer wood. As mentioned previously, many egg pouches are made in or near the terminal growth of twigs not more than one eighth of an inch in diameter, where there is insufficient wood to stand such wounds without disastrous results to both the twigs and the eggs deposited in them.

The eggs are inserted through the bark and much deeper into the wood than are the eggs of *S. inermis*. Although the eggs are deeply placed, the margins of the wounds are spread so wide that the tip ends of the eggs are often visible (fig. 7, *A*).

Counts of the eggs in 671 egg pouches showed a range of from 1 to 38 with an average of 19.9 (table 13).

TABLE 13.—*Number of eggs per pouch deposited by Ceresa basalis, Yakima, Wash., 1924–27*

| Number of eggs per pouch | Number of pouches | Number of eggs per pouch | Number of pouches | Number of eggs per pouch | Number of pouches | Number of eggs per pouch | Number of pouches |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 11 | 16 | 21 | 25 | 31 | 8 |
| 2 | 1 | 12 | 21 | 22 | 42 | 32 | 2 |
| 3 | 1 | 13 | 17 | 23 | 43 | 33 | 2 |
| 4 | 2 | 14 | 23 | 24 | 32 | 34 | 2 |
| 5 | 5 | 15 | 31 | 25 | 39 | 35 | 5 |
| 6 | 8 | 16 | 26 | 26 | 28 | 36 | 2 |
| 7 | 12 | 17 | 25 | 27 | 27 | 37 | 3 |
| 8 | 16 | 18 | 44 | 28 | 26 | 38 | 1 |
| 9 | 7 | 19 | 26 | 29 | 9 | | |
| 10 | 15 | 20 | 55 | 30 | 23 | | |

| | |
|---|---|
| Total pouches | 671 |
| Total eggs | 13, 334 |
| Average number of eggs per pouch | 19. 9 |

Repeated observations have failed to indicate that there is any difference in the method of oviposition between this species and that already described for *S. inermis*. Instead of cutting the supplementary slits, however, as in the case of *inermis*, this species withdraws the ovipositor after having cut the longitudinal slit, rests a few minutes, and then commences depositing her eggs as described for *S. inermis*, the first egg in the slit being placed in the end last completed. The length of time required in depositing an egg is about the same as for *inermis*, 45 to 60 seconds for each egg, but since on an average about 20 eggs are placed in each wound, instead of the 6 in the case of *inermis*, the time necessary for *C. basalis* to complete an egg pouch is about three times as long.

Because of difficulties encountered in rearing the insects, the egg-laying capacity of individual females was not ascertained. It seems probable, however, that they lay as many as *S. inermis*, which is reported (*17*) to lay as many as 252 eggs each.

## CERESA BUBALUS FAB.

The buffalo tree hopper, *Ceresa bubalus*, is rare, compared with *Stictocephala inermis* and *C. basalis*, in most places in the Yakima Valley. In certain other localities, however, it equals these in numbers, and in collections made at Parma, Idaho, *C. bubalus* predominated. Although this species is the largest of those studied and its injury more severe than that of *S. inermis*, it is so scarce in most localities that it is of less economic importance than either *S. inermis* or *C. basalis*. On account of its scarcity in the Yakima Valley few observations of importance were made upon it.

It is readily distinguished from *S. inermis* and *C. basalis* by its larger size and its large pronotal horns (fig. 14, *A;* pl. 4, *A*), and from *C. basalis* also by the lack of the dark coloring on the legs and ventral side of the body, which prevails in *basalis*.

### DISTRIBUTION

*Ceresa bubalus* is one of the most widely distributed of the Membracidae in this country, having been recorded in nearly all of the States, except those in the extreme Southeast, and from most of the

southern Canadian Provinces. It is generally recognized as perhaps the most injurious of all the Membracidae.

## SYNONYMY AND COMMON NAME

Fabricius (*8, p. 14*) described this species in 1794, placing it in Germar's *Membracis*. In 1803, however, he changed the species to the genus *Centrotus* (*9, p. 20*). In 1840 Blanchard (*2, p. 181*) changed it back to the genus *Membracis*, but in 1846 Fairmaire (*10, p. 286*) placed it again in the genus *Centrotus*. In 1851 Walker (*29, p. 531*) placed it tentatively in the genus *Ceresa*, an allocation which was confirmed by Uhler in 1862, as reported by Harris (*16, footnote, p. 221*).

This species is commonly called the "buffalo tree hopper" on account of its high pronotum and the hornlike projections of the anterior angles of the pronotum which give it a fancied resemblance to a male buffalo.

The more important synonymy is as follows:

*Membracis bubalus* Fabricius, 1794 (*8, p. 14*)
*Centrotus bubalus* Fabricius, 1803 (*9, p. 20*)
*Membracis bubalus* Blanchard, 1840 (*2, p. 181*)
*Centrotus bubalus* Fairmaire, 1846 (*10, p. 286*)
*Ceresa ? bubalus* Walker, 1851 (*29, p. 531*)
*Ceresa bubalus* Uhler, 1862 (*16, p. 221*)

## CHARACTER AND IMPORTANCE OF INJURY

The oviposition scars of *C. bubalus* are conspicuously different from those of either of the other species studied (pl. 6, *B*). The incisions are made in pairs, two short cuts semicrescentric and parallel, in each of which from 6 to 12 eggs are deposited. The cuts, which prevent the wood from growing over the wounds, increase in size from year to year, causing extremely ugly scars and roughened, gnarled twigs (pls. 5, *A*, *b*, and 6 *A*, *a*, *B*).

Badly infested twigs are dwarfed and weakened and so are easily broken by the wind. As in the case of the scars of the associated species *C. basalis*, these pronounced lesions often furnish suitable and convenient hiding places for the woolly apple aphid and for the overwintering eggs of the green apple aphid.

Goodwin and Fenton (*15*), in a histological study of the pathological changes produced in the plant tissue resulting from these malformations, determined that owing to the formation of corky layers of cells on either side of the lesions the wounds failed to heal and that as the surrounding wood continues to grow the wounds become deeper and wider, causing the wood between the cuts to slough off. They state:

> Altogether, mechanical injury is very severe and there are evidences that decay often sets in due to these wounds. While these may eventually heal over, the organisms have already entered the heartwood, and ultimately this secondary injury may kill the entire limb.

## FOOD PLANTS

The present studies of this species have been limited, and the nymphs have not been observed. It is probable, however, that their chief food plant in the orchard is alfalfa. They may also feed on sweetclover.

Funkhouser (*12*) reports *Ceresa bubalus* as common on grasses and low shrubs and as feeding upon succulent herbs, particularly sweet-

clover. Brittain (*3*) reports it as feeding upon sheep sorrel (*Rumex acetosella*), Canada thistle (*Cirsium arvensis*), clover (*Trifolium repens*), goldenrod (*Solidago* spp.), curled dock (*Rumex crispus*), plantain (*Plantago major*), and dandelion (*Taraxacum officinale*).

Severin (*25*) reports the adults as feeding and ovipositing upon apple, pear, plum, elm, poplar, willow, and boxelder trees; the nymphs as feeding on succulent weeds.

Pettit (*21*) has observed a species of tree hopper, probably *bubalus*, as seriously injurious in Michigan to 1-year-old and 2-year-old fruit trees set out in alfalfa land, while an adjoining lot of trees set in clean cultivated land was entirely free from infestation.

## COMPARISON OF OVIPOSITORS

The ovipositors of the three species, *Stictocephala inermis*, *Ceresa basalis*, and *C. bubalus*, were examined, inasmuch as these three species

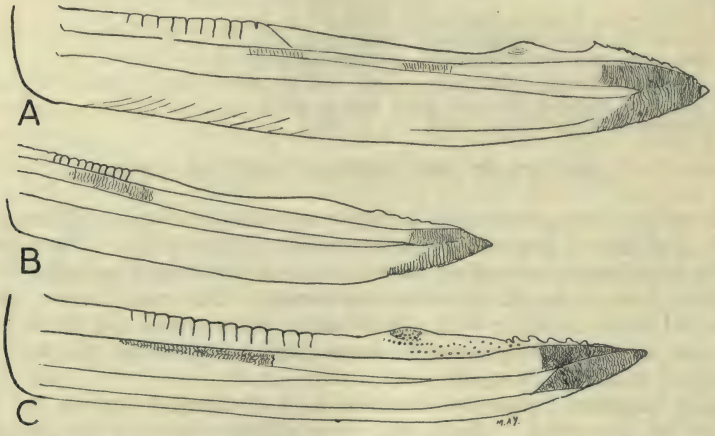



FIGURE 15.—Ovipositors: *A*, *Ceresa basalis*; *B*, *Stictocephala inermis*; *C*, *Ceresa bubalus*. All × 25.

make quite distinct incisions in which to deposit their eggs. Although *C. basalis* is the smallest of the three, it has the longest ovipositor (fig. 15, *A*) and makes the deepest incision. *Stictocephala inermis*, which makes the most superficial incision, has the shortest ovipositor (fig. 15, *B*), and *C. bubalus*, the largest of the three species, which makes the double, medium deep cuts, has an ovipositor midway in length between those of the other two (fig. 15, *C*). The average length of several ovipositors of each species was found to be as follows: *C. basalis*, 3.7 mm; *C. bubalus*, 3.4 mm; and *S. inermis*, 2.7 mm. The ovipositors of the species of *Ceresa* are also somewhat broader than that of *S. inermis*.

The sharp sawlike edge of the tip of the ovipositor readily accounts for the ability of the females to cut their oviposition lesions

## CERESA ALBIDOSPARSA STÅL

In March 1927, 1-year-old seedling pear trees were found with membracid eggs inserted in the buds. It was apparent that these must be the eggs of some species other than those previously studied. Samples of these twigs were brought to the laboratory and kept for

observation and hatching of the eggs. The eggs proved to be those of *Ceresa albidosparsa*.

## DISTRIBUTION

*C. albidosparsa* Stål is recorded by Funkhouser (*13*) as occurring in California, Nevada, Texas, and British Columbia. This is therefore the first published record of its occurrence in the Pacific Northwest. It is probably a western species, since there is no record of its having been found elsewhere. It is probable that it is harmless, since its eggs are deposited in the buds, where apparently they cause little, if any, damage.

## HISTORY

*Ceresa albidosparsa* was originally described by Stål in 1869 (*26, p. 245*), since which time it has been referred to only eight times in entomological literature. These references are all under the name given above, as this tree hopper has not been confused with other species or described under any other names. Little is known of its life history and habits, and it has no common name.

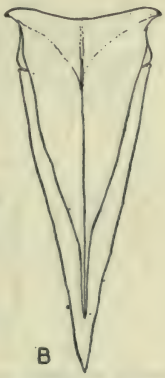



FIGURE 16.—*Ceresa albidosparsa*: *A*, Front view; *B*, dorsal view. ×6.

## DESCRIPTION OF ADULT

Pale green; 8 mm in length; with short, curved, red-tipped pronotal horns (fig. 16).

## POSITION OF EGGS

The eggs are deposited singly or in small groups of 2 or 3 in the buds, either at the base or among the bud scales (fig. 17). Most of them are placed in terminal buds or in buds close to the tips of the twigs. As many as a dozen eggs may be found in a single bud, though usually there are only about half that number.

FIGURE 17.—Eggs and empty hatching membranes of *Ceresa albidosparsa* in buds of 1-year-old seedling pear tree. ×2.

## HATCHING

Just previous to hatching, the eggs protrude from the bud about two thirds of their length. This may be partly due to the effect of the extending bud scales, which at this time are pushing out rapidly.

The time required for the emergence of the nymphs from the eggs was about 13 minutes in the few cases observed.

The eggs of *C. albidosparsa* seem to hatch earlier in the morning than the eggs of other species observed. Possibly this is due to the fact that increasing temperatures can more readily affect the eggs in their semiexposed position in the buds than is possible with those within the bark and outer wood.

### NYMPHAL INSTARS

Several nymphs in vials were reared through the first instar on alfalfa. These are readily distinguished from the first-instar nymphs of other species by their much lighter color, yellowish heads, and white eyes. The agility of their movements also readily distinguished them from all other species. While nymphs of other species walked slowly from place to place, these darted here and there with apparent haste.

A close study of the arrangement of tuberosities and hairs on the head and face of newly hatched nymphs (fig. 18) revealed nothing especially different from their arrangement in other species, particularly *C. basalis* (fig. 8, *B*). Except for the white eyes and the cream-yellow color of the head, these nymphs resembled those of the other species studied.

Nymphs hatched from April 16 to 26, 1927, from twigs kept since March 29 in the laboratory, at room temperature. Outdoor hatching occurred from May 6 to 10. From these one adult reached maturity on July 18, after passing through the five instars characteristic of the other species of Membracidae. Moltings took place as follows: May 24–25, June 3–6, June 9–11, June 20–25, and July 18. The total length of the period of the nymphal instars was between 69 and 73 days.

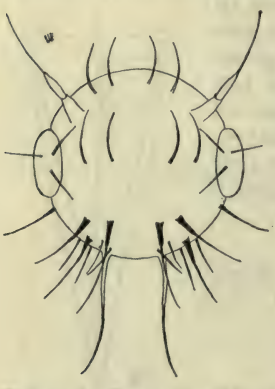


FIGURE 18.—Front view of head and face of first instar nymph of *Ceresa albidosparsa*. ×45.

### HELIRIA RUBIDELLA BALL

*Heliria rubidella* was first described by Ball (*1, p. 28*) from Colorado in 1918. Since 1926 it has been found in considerable numbers on apple trees at Wenatchee, Wash., as reported by Yothers, Webster, and Spuler in 1929 (*35, p. 269*) and by the writer in 1930 (*33, p. 1, 2, 12; 34, p. 15*).

The eggs of this membracid are laid in the apple twigs, one in each of two more or less closely placed parallel slits.[3]

The nymphs hatch late in April and early in May. Unlike other species studied, the nymphs do not fall to the ground upon emerging, but remain on the twigs throughout their nymphal stages, feeding upon the plant juices and reaching maturity in early June.

The adults (pl. 7, *A–E*) feed, mate, and oviposit on the twigs, spending most of their lives there except for rare flights to neighboring trees. Inasmuch as the insects do not feed upon the cover crop or deposit their eggs in any of the cover-crop plants, it is evidently of no consequence in the life of the insect.

Hundreds of individuals (pl. 7, *E*) are sometimes found on sickly branches of apple trees, particularly of the Stayman Winesap variety. This, at first, seemed to indicate that these insects were responsible for the unhealthy condition of the branches (pl. 8). Later, however, it was decided that the presence of the insects was probably due to an especially attractive odor given off by the limbs and that the presence

[3] The writer is indebted to P. B. Allen, Jr., temporary assistant at the Wenatchee, Wash., laboratory of the Bureau of Entomology from 1930 to 1932, for this discovery and for other observations on this species which had not yet been reported.

of the insects was a result and not the cause of the trouble, although the insects do feed upon the sick branches, thereby doubtless hastening their death.

## ASSOCIATED SPECIES OF MEMBRACIDAE

The following associated species have been recorded from specimens collected in these studies, from other collections, and from literature: *Ceresa albidosparsa*,[4] *C. basalis*, *C. borealis* Fairm.,[4] *C. brevis* Walk.[4] (fig. 14, *E*), *C. bubalus*,[4] *C. femorata* Fairm.,[4] *C. taurina* Fitch.,[4] *Stictocephala franciscana* Stål, *S. inermis*,[4] *S. pacifica* Van D. (fig. 14, *C*), *S. wickhami* Van D. (fig. 14, *F*), *Campylenchia latipes* Say, and *Heliria rubidella* Ball.[4]

*Stictocephala pacifica*, according to Van Duzee,[5] probably does not occur in the interior country of the Pacific coast at all, and records of this species in the interior districts of Washington, Idaho, Oregon, or British Columbia are probably based on erroneous identifications. *Stictocephala wickhami*, while recognized by some students of these groups, and found in collections as such, is probably comparatively rare, or is not readily separated from *inermis*. *Ceresa brevis* is represented by a few specimens determined by Van Duzee from Idaho, which had previously been determined as *C. borealis*. Funkhouser [5] has recognized both *C. femorata* and *C. taurina*.

*Campylenchia latipes* has been found in considerable numbers throughout the Pacific Northwest wherever observations have been made upon species of the genera *Ceresa* and *Stictocephala*. Like them, it is found on the alfalfa cover crop in orchards, upon which it feeds throughout its nymphal stages and also as an adult. This species has been observed incidentally from time to time in the studies of the other forms. Individuals of this species reach maturity earlier than the other membracids, adults having been taken as early as June 9, and in considerable numbers by June 19.

## DISSEMINATION

Although capable of flight, tree hoppers are not ordinarily seen flying about in the fields and orchards, although when disturbed, as by the approach of a person, they take flight so suddenly that it is often difficult to watch their movements. They seldom fly higher than 8 or 10 feet, or farther than 100 feet at one flight. The distance flown by a number observed was about 50 to 75 feet. Presumably they fly considerable distances during their 60 or more days of adult life. This is apparently their only natural means of dissemination, since in their nymphal instars they never move even from one plant to another.

Infestation of new areas, at least at considerable distances, is probably very largely through egg-infested nursery stock and graft scions. In the adult stage the insects might occasionally be carried by vehicles passing through orchards or fields, or in fruit boxes or on other orchard equipment. Since the adults are extremely shy, however, it is very improbable that they are often distributed in this way.

[4] Not recorded by Funkhouser (*13*) as occurring in the Pacific Northwest (Washington, Oregon, and Idaho).

[5] In correspondence with the writer.

## THE RELATION OF ANTS TO NYMPHS

Much has already been written by others upon the interesting subject of attendance of ants upon the nymphs and adults of membracids. Funkhouser (*12*) reports that while individuals of the genera *Ceresa* and *Stictocephala* have been known to be attended by ants, the latter genus has never been known to give off the anal fluid. The writer has observed attendance by ants upon *Stictocephala inermis* and *Ceresa basalis* in outdoor rearing cages set over alfalfa plants. Probably more than one species of ant attends the nymphs in this part of the country, but only one species has been definitely determined (*Myrmica rubra scabrinodis* var. *sabuleti* Meinert).

Considerable numbers of this species of ant have been observed associating with the nymphs in the cages mentioned. They were observed waving their antennae and stroking the posterior extremities of second, third, and fourth instar nymphs, causing the nymphs to void a clear, colorless liquid from the anal aperture, which the ants then proceeded to feed upon with apparent relish.

## NATURAL CONTROL

Mention has already been made of the natural mortality to which the egg stage, especially of *C. basalis*, is subject. In the nymphal stages the tree hoppers are also subject to a considerable mortality. In dropping from the trees, in the twigs of which the eggs are laid, many nymphs fall on, or are blown by the wind to, utterly barren ground and are unable to reach suitable food plants; still others fall into irrigation ditches and are lost. Of the many, many thousands of nymphs that hatch from each tree in heavily infested orchards, only a comparatively few survive and reach maturity.

### PARASITES

Two species of hymenopterous egg parasites, *Gonatocerus* n. sp.[6] and *Tetrastichus* sp.,[7] have been reared from the eggs of *Stictocephala inermis;* but since these are so rare they affect little control.

### OTHER ENEMIES

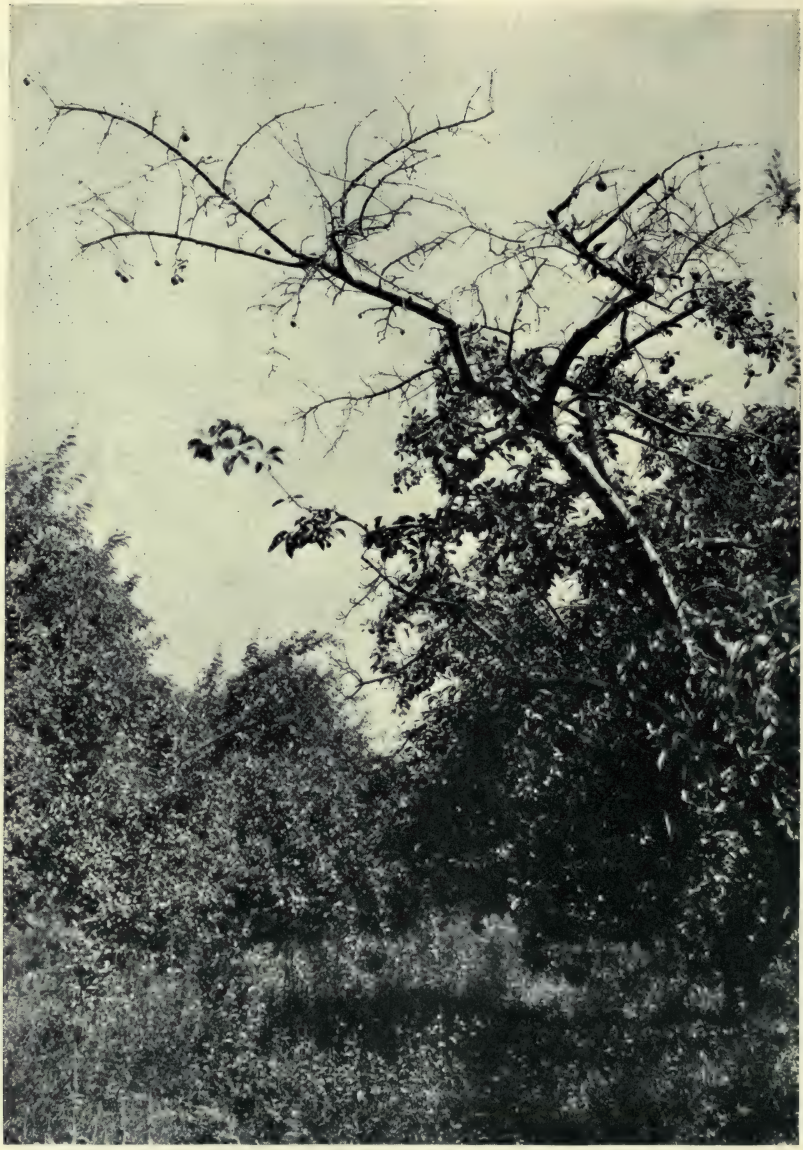
Of the various species of spiders observed feeding upon the hatching eggs and emerging nymphs, two species have been determined as *Philodromus minuta* Bks.[7] and *Dendryphantes militaris* Hentz.[7] These spiders and other undetermined species are commonly observed throughout the hatching period upon the twigs from which *S. inermis* nymphs are emerging, and have often been seen devouring the tender young nymphs while they were emerging from the eggshells.

A species of mite belonging to the genus *Seius* [8] was found in considerable numbers associated with the overwintering tree-hopper eggs, and was doubtless responsible for the destruction of a great many of the eggs, inasmuch as discolored, empty, shriveled eggshells were almost always associated with the presence of these mites in the egg pouches.

[6] Determined by A. B. Gahan.
[7] Determined by A. R. Shoemaker.
[8] Determined by H. E. Ewing.

HELIRIA RUBIDELLA BALL.

A, Side view. B, Dorsal view. C, Frontal view. ×4. D, Fifth-instar nymph, *a*, and adult, *b*. ×1¼. E, Characteristic group of adults on apple twig. ×¼.



Dying branch of Stayman Winesap apple tree at Wenatchee, Wash., characteristic of type of tree infested by *Heliria rubidella*.

At least two coccinellids, *Adalia bipunctata* L.[9], and *Hyperaspis quadrivittata* Lec.[10] have been observed feeding upon the hatching nymphs. Both of these have been seen devouring numbers of the emerging nymphs, one after another, within a few minutes' time.

A single specimen of *H. quadrivittata* was placed in a Petri dish at 1:15 p.m. and given 20 newly hatched nymphs for food. It ate 15 of them during the first 15 minutes, and still others during the next 15 minutes. At 2:15 it was given 20 more nymphs, several more of which it had eaten by 3:15.

An ant, *Formica fusca fusca* var. *argentia* Wheeler [10], has been noted a number of times eating the hatching nymphs.

Another ant, *Myrmica rubra scabrinodis* var. *sabuleti* Meinert, was often seen in the cages carrying portions of dead nymphs about in its mouth, although it was not actually seen eating them. It is reasonable to suppose that ants are responsible for the death of many of the nymphs, since they are invariably associated with them, and the mortality of the nymphs is very high.

Adults of *Ceresa bubalus*, *C. basalis*, and *Stictocephala inermis* collected at Parma, Idaho, in August 1924 were badly infested with a red mite, determined by H. E. Ewing as "parasitic larvae of the genus *Achorolophus* of the family Erythraeidae." Great numbers of these mites were present under the tegmina and on most of the ventral spaces on the body. It was noted that the more heavily infested individuals were comparatively sluggish and therefore more readily captured by hand. Only rarely have these mites been found on membracids in the Yakima Valley.

Coccinellid and syrphid larvae of undetermined species have been observed feeding upon the hatching nymphs in the orchard.

Other species of predatory insects, such as those of the genera *Hemerobius*, *Chrysopa*, and *Oecanthus*, doubtless feed upon the emerging nymphs, since they are occasionally present during the last part of the hatching season.

No observations have been made as to whether birds feed upon the tree hoppers under discussion, but Wildermuth (*30*) records several species of birds as feeding upon *S. festina* in alfalfa fields in Arizona. *S. festina* is considerably smaller than any of the species studied here, but it is probable that a few individuals of these larger species are devoured by certain birds. Wildermuth also records toads as predatory on *S. festina*, and it is probable that toads also help check the increase of the northwestern species.

## NATURAL PROTECTION

Little protective resemblance can be claimed for the shape of the species here discussed, at least under their present acquired environment. The general green color, however, gives them certain protection among the green food plants upon which they feed, and among which they spend most of their lives. This greenish coloring also may be of incidental protection to them while they are resting on the petioles of leaves and on the leaves themselves, but it probably is of little value to them when they are on the twigs ovipositing or resting.

[9] Determined by H. S. Barber.
[10] Determined by S. A. Rohwer.

The habit of remaining quiet for hours at a time is doubtless of no little protective value to the adults.

The almost universal position assumed by the nymphs of *Heliria rubidella* behind the buds, which they closely resemble in both color and shape, evidently affords them considerable protection.

The habit of nymphs and adults of stepping rapidly around to the opposite side of the twig or other object, when disturbed, is also of protective value.

The hard pronotum with its sharp posterior end and, in the species of *Ceresa*, the more or less sharp humeral horns doubtless afford considerable protection.

As Wildermuth (*30*) has pointed out, the habit of exploding a bubble of liquid from the tip of the abdomen when disturbed is probably also of protective value when this bubble is exploded in the face of an enemy.

## PREVENTIVE AND CONTROL MEASURES

### SPRAYING AGAINST THE EGGS

Lovett (*18*) suggested the use of 8 gallons of a heavy miscible oil to 100 gallons of water, but expressed a reasonable doubt that such a spray could reach the egg masses hidden underneath the bark. The studies conducted by the writer, as indicated earlier in this bulletin, have shown that the eggs of the tree hoppers are sufficiently exposed to be reached by contact sprays, and numerous tests were conducted with such materials.

#### LABORATORY TESTS

Tests of various materials of possible value against the eggs of *Stictocephala inermis* were conducted in the laboratory in 1923 and 1924. Twigs containing tree-hopper eggs were brought in from the orchard and were sprayed with such materials as were being tested in certain experiments (*19*) for the control of red spiders [11] and the San Jose scale.[12] Spraying was done with a hand atomizer, the twigs being thoroughly drenched on all sides, after which they were placed with their cut ends in jars of water and kept until sufficient time had elapsed for the eggs to hatch. The results of these tests, which are shown in tables 14 and 15, indicated that lime-sulphur at the usual dormant strength is not very effective against the eggs of the tree hoppers, that lubricating oil emulsions at 4 percent of actual oil showed a mortality of 90 to 100 percent (including mortality from natural causes); that miscible oils are as effective (at equivalent strengths) as the lubricating-oil emulsions; that the distillate oils are less effective than the more viscous lubricating oils; and that kerosene emulsion at 8 to 16 percent is about equivalent to the lubricating-oil emulsions at 4 percent. It was also evident that applications made while the eggs were dormant were fully as effective as applications made as time for hatching approached.

[11] *Paratetranychus pilosus* C. and F. and *Bryobia praetiosa* Koch.
[12] *Aspidiotus perniciosus* Comst.

TABLE 14.—*Laboratory tests of dormant sprays on the eggs of Stictocephala inermis, Yakima, Wash., 1923*

| Test | Materials used | Dilution | Date eggs were— | | Total eggs | Condition of eggs at count | | |
|---|---|---|---|---|---|---|---|---|
| | | | Sprayed | Counted | | Hatched | Dead | |
| | | | | | *Number* | *Number* | *Number* | *Percent* |
| A | Lime-sulphur (26° Baumé) concentrate | °*Baumé* 3 | Mar. 17 | May 15 | 289 | 147 | 142 | 49.1 |
| B | do | 4 | do | May 16 | 351 | 113 | 238 | 67.8 |
| C | do | 5 | do | May 17 | 449 | 89 | 360 | 80.2 |
| D | Lubricating-oil emulsion (soap emulsifier) | *Percent oil* 2 | Mar. 14 | May 12 | 272 | 93 | 179 | 65.8 |
| E | do | 4 | do | do | 269 | 0 | 269 | 100.0 |
| F | Material used in test D, plus ¼ percent cresol [1] | 2 | do | May 4 | 379 | 64 | 315 | 83.1 |
| G | Material used in test D, plus ½ percent cresol | 2 | do | May 12 | 179 | 24 | 155 | 86.6 |
| H | Material used in test D, plus 1 percent cresol | 2 | do | do | 338 | 28 | 310 | 91.7 |
| I | Material used in test E, plus ¼ percent cresol | 4 | do | May 4 | 440 | 0 | 440 | 100.0 |
| J | Material used in test E, plus ½ percent cresol | 4 | do | May 12 | 306 | 0 | 306 | 100.0 |
| K | Material used in test E, plus 1 percent cresol | 4 | Mar. 17 | May 15 | 342 | 0 | 342 | 100.0 |
| L | Material used in test E, plus 6 percent cresol | 6.5 | Mar. 14 | May 12 | 340 | 0 | 340 | 100.0 |
| M | Crude oil emulsion | 2.67 | Mar. 17 | May 17 | 438 | 64 | 374 | 85.4 |
| N | do | 6.67 | do | do | 348 | 8 | 340 | 97.7 |
| O | do | 10 | do | do | 350 | 33 | 317 | 90.6 |
| P | Crude oil emulsion, plus ½ percent cresol | 2.67 | do | do | 267 | 7 | 260 | 97.4 |
| R | Commercial distillate-oil emulsion | 4.1 | do | do | 385 | 182 | 203 | 52.7 |
| KK | Kerosene emulsion | 8 | Mar. 20 | May 2 | 362 | 27 | 335 | 92.5 |
| ZZ | do | 16.67 | do | do | 280 | 20 | 260 | 92.9 |
| CK | Untreated | | | Apr. 30 / May 2 | 952 | 791 | 161 | 16.9 |

[1] The cresol used was cresylic acid, 97–99 percent, pale.

TABLE 15.—*Laboratory tests of dormant sprays on the eggs of Stictocephala inermis, Yakima, Wash., 1924* [1]

SPRAYED MAR. 7, EXAMINED MAY 1

| Test no. | Material used | Dilution | Total eggs | Condition of eggs at count | | |
|---|---|---|---|---|---|---|
| | | | | Hatched | Dead | |
| | | °*Baumé* | *Number* | *Number* | *Number* | *Percent* |
| 1 | Lime-sulphur (30° Baumé concentrate) | 4 | 225 | 135 | 90 | 40.0 |
| 2 | do | 5 | 220 | 125 | 95 | 43.2 |
| | | *Percent oil* | | | | |
| 3 | Lubricating-oil (brown neutral) emulsion (soap emulsifier) | 2 | 260 | 55 | 205 | 78.8 |
| 4 | Lubricating-oil (red engine) emulsion (soap emulsifier) | 2 | 295 | 70 | 225 | 76.3 |
| 5 | do | 3 | 315 | 65 | 250 | 79.4 |
| 6 | do | 4 | 240 | 20 | 220 | 91.7 |
| 7 | Lubricating-oil (red engine) emulsion (casein-lime emulsifier) | 2 | 220 | 45 | 175 | 79.5 |
| 8 | Miscible oil | 2 | 185 | 35 | 150 | 81.1 |
| 9 | do | 3 | 315 | 20 | 295 | 93.7 |
| 10 | Commercial lubricating-oil (brown neutral) emulsion | 2 | 280 | 50 | 230 | 82.1 |
| 11 | Commercial spray oil | 2.3 | 230 | 55 | 175 | 76.1 |
| 12 | do | 4 | 235 | 25 | 210 | 89.4 |
| 13 | Untreated | | 315 | 250 | 65 | 20.6 |

[1] For specifications of spray materials see U.S. Dept. Agr. Tech. Bul. No. 25, pp. 29–32 (*19*).

TABLE 15.—*Laboratory tests of dormant sprays on the eggs of Stictocephala inermis, Yakima, Wash., 1924*—Continued

SPRAYED APR. 4, EXAMINED MAY 15–17

| Test no. | Material used | Dilution | Total eggs | Condition of eggs at count | | |
|---|---|---|---|---|---|---|
| | | | | Hatched | Dead | |
| | | *°Baumé* | *Number* | *Number* | *Number* | *Percent* |
| 68 | Lime-sulphur (30° Baumé concentrate) | 5 | 186 | 112 | 74 | 39.8 |
| R | ....do | 6 | 376 | 167 | 209 | 55.6 |
| | | *Percent oil* | | | | |
| 69 | Lubricating-oil (brown neutral) emulsion (soap emulsifier) | 2 | 227 | 44 | 183 | 80.6 |
| U | Lubricating-oil (brown neutral) emulsion (soap emulsifier) | 3 | 427 | 6 | 421 | 98.6 |
| 70 | Lubricating-oil (red engine) emulsion (soap emulsifier) | 2 | 266 | 37 | 229 | 86.1 |
| 71 | Lubricating-oil (red engine) emulsion (casein-lime emulsifier) | 2 | 233 | 55 | 178 | 76.4 |
| 72 | ....do | 3 | 281 | 48 | 233 | 82.9 |
| 73 | Miscible oil | 2 | 254 | 42 | 212 | 83.5 |
| Y | ....do | 3 | 404 | 0 | 404 | 100.0 |
| AA | ....do | 4 | 320 | 25 | 295 | 92.2 |
| BB | Miscible oil, plus nicotine sulphate 1:600 | 4 | 662 | 5 | 657 | 99.2 |
| 75 | Commercial oil emulsion | 2 | 170 | 54 | 116 | 68.2 |
| 76 | ....do | 3 | 414 | 18 | 396 | 95.7 |
| CC | Untreated | ..... | 386 | 227 | 159 | 41.2 |

A somewhat higher percentage of kill was obtained in the laboratory than in the field, partly because of the more thorough application of the spray. It is also possible that the slower evaporation under indoor conditions is conducive to greater penetration, and consequent greater lethal effect upon the insect.

### ORCHARD TESTS

The results of field tests of various materials conducted in 1923 and 1925 are given in tables 16 and 17. In 1923 applications were made at two different times, first when the eggs were dormant, and later about a week before they began to hatch. While the percentages of kill in the field were somewhat lower, results were in general agreement with those obtained in the laboratory. The lubricating-oil sprays at a 4 percent strength, with or without the addition of lime-sulphur or of nicotine, were found quite effective in killing most of the eggs. Lime-sulphur at a 4° Baumé strength, on the other hand, appeared to be of little value.

TABLE 16.—*Orchard tests of dormant sprays on the eggs of Stictocephala inermis, Yakima, Wash., 1923*

[Applications made with a power sprayer]

PLOT 1. SPRAYED MAR. 29, COUNTED MAY 19–22

| Test no. | Material used | Dilution of actual oil | Total eggs | Condition of eggs at count | | |
|---|---|---|---|---|---|---|
| | | | | Hatched | Dead | |
| | | *Percent* | *Number* | *Number* | *Number* | *Percent* |
| 1 | Lubricating-oil emulsion | 2 | 351 | 206 | 145 | 41.3 |
| 2 | Lubricating-oil emulsion, plus ¼ percent cresol | 2 | 419 | 181 | 238 | 56.8 |
| 3 | Lubricating-oil emulsion, plus ½ percent cresol | 4 | 400 | 103 | 297 | 74.2 |
| 4 | Distillate-oil emulsion | 6 | 264 | 149 | 115 | 43.6 |
| 5 | Untreated | ..... | 381 | 334 | 47 | 12.3 |
| | PLOT 2. SPRAYED APR. 10, COUNTED MAY 23–25 | | | | | |
| 1 | Lubricating-oil emulsion | 2 | 345 | 200 | 145 | 42.0 |
| 2 | Lubricating-oil emulsion, plus ¼ percent cresol | 2 | 360 | 209 | 151 | 41.9 |
| 3 | Lubricating-oil emulsion, plus ½ percent cresol | 4 | 511 | 53 | 458 | 89.6 |
| 4 | Miscible oil | 3 | 442 | 108 | 334 | 75.6 |

TABLE 17.—*Orchard tests of dormant sprays on the eggs of Stictocephala inermis in sprouts growing from the bases of tree stumps, Yakima, Wash., 1925*

[Sprayed with a bucket pump Apr. 7, examined May 13]

| Test no. | Material as used | Total eggs | Condition of eggs at count | | |
|---|---|---|---|---|---|
| | | | Hatched | Dead | |
| | | *Number* | *Number* | *Number* | *Percent* |
| 1 | Lime-sulphur (28° Baumé concentrate) diluted to 4° Baumé | 495 | 350 | 145 | 29.3 |
| 2 | Lubricating-oil (brown-neutral) emulsion (casein-lime emulsifier) at 3 percent actual oil | 355 | 50 | 305 | 85.9 |
| 3 | Same material as test 2, at 4 percent actual oil | 560 | 40 | 520 | 92.9 |
| 4 | Material used in test 2, plus lime-sulphur (28° Baumé concentrate), the mixture to read 2° Baumé | 545 | 35 | 510 | 93.6 |
| 5 | Material used in test 2, plus lime-sulphur (28° Baumé concentrate), 1 gallon to 50 gallons | 540 | 5 | 535 | 99.1 |
| 6 | Material used in test 2, but at 6 percent actual oil, plus nicotine sulphate (40 percent), 1 part to 1,000 parts of the emulsion | 525 | 0 | 525 | 100.0 |
| 7 | Same as test 6, but with 3 percent actual oil | 552 | 27 | 525 | 95.1 |
| 8 | Untreated | 305 | 250 | 55 | 18.0 |

No tests were made separately on the eggs of *C. basalis*, but counts were made of the eggs from orchards which had been given the regular dormant sprays for the control of the San Jose scale in early spring. In one orchard a 4 percent oil emulsion was used throughout, and in the second orchard a 4 percent oil emulsion was used in part of the acreage and lime-sulphur (4° Baumé) was used in the rest. The results of these counts are shown in table 18.

TABLE 18.—*Eggs of Ceresa basalis killed by orchard spraying for the San Jose scale, Yakima, Wash., 1925*

| Treatment | Date eggs examined | Condition of eggs | | | | Dead or overgrown [1] |
|---|---|---|---|---|---|---|
| | | Alive | Hatched | Dead | | |
| | | *Number* | *Number* | *Number* | *Percent* | *Percent* |
| Engine-oil emulsion, 4 percent | Apr. 29 and May 5. | 988 | 88 | 2,594 | 70.68 | ------ |
| Check | ----do---- | 455 | 50 | 140 | 21.71 | ------ |
| Engine-oil emulsion, 4 percent | May 1 | 270 | 15 | 560 | 66.27 | ------ |
| Lime-sulphur, 4° Baumé | ----do---- | 450 | 20 | 255 | 35.17 | ------ |
| Check | ----do---- | 416 | 62 | 177 | 27.02 | ------ |
| Engine-oil emulsion, 4 percent | May 15 [2] | 135 | 65 | 870 | 81.31 | 93.93 |
| Lime-sulphur, 4° Baumé | ----do---- | 150 | 370 | 225 | 30.20 | 50.34 |
| Check | ----do---- | 70 | 775 | 175 | 17.16 | 24.02 |

[1] Eggs overgrown are considered as dead in records for control.
[2] All eggs that could hatch had hatched by this date.

A factor to be considered in interpreting these results is that the portions of the trees where eggs of *C. basalis* were deposited, i.e., in sprouts growing about the base of the tree and in the terminal twigs of the low-hanging branches, are the portions of the trees most often slighted in the spraying.

## SPRAYING AGAINST THE NYMPHS

Funkhouser (*12*) suggested the use of contact sprays against the soft-bodied nymphs, and this was tested in 1923. The alfalfa in four orchard blocks was sprayed with a power outfit on May 2, when

the alfalfa was 12 to 18 inches high and the tree-hopper eggs had nearly all hatched. Four different materials were used in the plots as follows: (1) Nicotine sulphate 1 to 800 with a casein-lime spreader, one half pound in 50 gallons; (2) nicotine sulphate 1 to 800 in a 1 percent lubricating-oil emulsion; (3) lubricating-oil emulsion, 1 percent; and (4) lubricating-oil emulsion, 2 percent. No noticeable control resulted in any of the plots, probably because of the difficulty in wetting the lower portions of the plants, where the young nymphs feed. If the spraying could be done immediately after the alfalfa has been cut, it might be possible to wet the plants far enough down within the crowns to kill the nymphs, but this method promises little value.

## CLEAN CULTURE

Since these membracids, with the exception of *Heliria rubidella*, feed exclusively throughout the nymphal period upon the more succulent vegetation growing in the orchard, such as alfalfa, sweetclover, and weeds, it is apparent that the elimination of all such food plants will be an effective control measure. Repeated observations made in the Yakima Valley have shown that orchards which are free of weeds suffer very little tree-hopper infestation except in trees on borders adjacent to alfalfa fields. Few instances were observed in which the hoppers traveled more than two tree rows from suitable food and protection, such as weeds or cover crops.

In the arid districts of the Pacific Northwest, however, a cover crop of some kind, usually alfalfa, has been found almost essential from the standpoint of general horticultural practice, and the loss sustained by the total elimination of cover crops would far exceed the gain from the repression of the tree hoppers. If other control measures were not available, however, the temporary elimination of cover crops might be worth considering in the case of a serious infestation.

If clean culture is likely to be practiced later on, sweetclover is preferable to alfalfa as a cover crop. Alfalfa is very persistent after once becoming established, and difficult to eliminate by cultivation. Sweetclover, on the other hand, is readily eliminated after the first two seasons.

## OTHER POSSIBLE CONTROL METHODS

The pruning out and destruction of infested twigs is sometimes advised. In cases of severe infestation this is obviously impractical, and in the case of young trees it would often mean the removal of the entire tree. In light infestations, on the other hand, the tree hoppers are seldom sufficiently injurious to warrant the effort. In the course of the regular pruning process, however, any infested twigs noted might well be removed.

The use of hopperdozers, which has been suggested, for controlling the adult tree hoppers in alfalfa fields was reported by Wildermuth (*30*) as impracticable, as but a small part of the hoppers were captured. Hopperdozers would be altogether impractical in orchards, even if they were otherwise successful, on account of the presence of the trees and because the cover crop of uncut alfalfa or sweetclover would not permit their use at any time when the adults were present.

## SUMMARY AND CONCLUSIONS

Considerable injury to fruit trees in the Pacific Northwest is caused annually by the egg-laying activities of several species of Membracidae commonly known as "tree hoppers." The more important of these, in the order of their economic significance, are *Stictocephala inermis*, *Ceresa basalis*, and *C. bubalus*. The last, the buffalo tree hopper, is generally credited with the injury caused by them all, but it is less important in the Pacific Northwest than either of the other two.

In the nymphal stages these membracids feed upon the alfalfa or sweetclover and possibly upon some of the succulent weeds growing in the orchards.[13] Their feeding upon these plants has caused no noticeable injury. The damage they cause results from the wounds cut into the twigs of fruit trees for the purpose of oviposition.

Eggs are deposited in apple, cherry, peach, pear, prune, willow, locust, poplar, and many other kinds of trees and shrubs. For the most part 1- and 2-year-old wood is used for egg deposition. An exception to this is the choice of the current season's growth by *C. basalis*.

Although the incisions are usually small, there are so many of them in cases of severe infestation that the growth of the tree is retarded. This is especially serious with 1- and 2-year-old trees. In the case of *C. basalis* the deep wounds made for egg deposition in the terminal portions of the twigs often cause these twigs to wither and die back for several inches.

The scars furnish suitable feeding places for the woolly apple aphid (*Eriosoma lanigerum*). The irritation caused by these aphids prevents the wounds from healing, and the unhealed wounds furnish entrance for fungous and other diseases.

The insects winter over in the egg stage only. These eggs are deposited from July to early October and hatch in April and early May the following spring. Upon hatching, the nymphs, excepting those of *Heliria rubidella*, fall to the alfalfa or such other cover crop or weeds as may be present. There they feed and pass through five instars, reaching maturity late in June or in July. The adults live about 60 days.

*Ceresa bubalus* deposits from 6 to 12 eggs in two short, parallel rows; *C. basalis*, about 20 eggs in straight, deep, longitudinal wounds; *Stictocephala inermis* deposits about 6 eggs in each tiny superficial scar; *C. albidosparsa* deposits eggs singly in buds; and *Heliria rubidella* deposits them singly in the bark.

Besides these species, there are several others associated with them, some of which are not readily distinguishable from them, but owing to their scarcity they are of little economic importance.

Of the various methods of control suggested or tried, spraying the eggs with a 4-percent oil emulsion or miscible oil is the most practical and satisfactory measure. While it is rarely possible to kill all of the eggs, the dormant oils destroy enough to accomplish reasonable control. Such applications are regularly put on for the control of the San Jose scale and European red mite, and extra applications for the tree-hopper eggs are unnecessary. Lime-sulphur proved ineffective.

Clean cultivation is worth consideration as a last resort in cases of severe injury where the use of oil sprays is undesirable.

[13] Except *Heliria rubidella*, which feeds upon the fruit-tree twigs.

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# DESCRIPTIONS OF SOME NATIVE TRYPETID FLIES WITH NOTES ON THEIR HABITS

BY

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Bureau of Entomology

UNITED STATES DEPARTMENT OF AGRICULTURE, WASHINGTON, D.C.

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## INTRODUCTION

The intensive inspections made in connection with the campaign to eradicate the Mediterranean fruit fly, *Ceratitis capitata* Wied., from Florida resulted in the collection of thousands of larvae and puparia of native flies belonging to the same family, the Trypetidae. Many of these represented little-known species of which the immature stages had neither been described nor associated with the adults. To make certain of identity, and thus avoid any possibility of confusion, some immature specimens of each different species were, as far as possible, reared to adults. Most of this rearing was done by D. J. Nicholson, working under the research unit. These rearings and the accurate, detailed biological notes made by Mr. Nicholson, form, in large part, the basis of this work. Only a comparatively

small percentage of the specimens discussed were reared by the writer or received from other sources.

The purpose of this publication is to describe these native species of trypetid flies, and discuss their classification so that they may be recognized from the immature stages, as well as from the adult flies. To make the text more accurate and complete, the types, as well as other specimens, in the collections of the United States National Museum, the Museum of Comparative Zoology at Cambridge, Mass., and the American Museum of Natural History in New York City have been studied and the results of these studies included.

## RELATIONSHIPS AND STRUCTURAL CHARACTERS

Adult Trypetidae have three-jointed antennae, each antenna with a dorsal arista. The head usually possesses well defined frontal and other bristles, some of which may be obsolescent (but obsolescent in only one North American genus, *Toxotrypana*, which is so unique that it is easily recognized). The thorax has the transverse suture not completed across the dorsum. All possess a pair of wings, each of which has only a single marginal and single submarginal cell, or, in other words, only two veins running to the wing margin between the spined first vein and the first posterior cell, the latter easily recognized because of being separated from the first basal cell by the anterior cross vein; the auxiliary vein closely follows the course of the first vein, often appearing basally fused thereto, until sharply bent toward the costa; the anal cell is often drawn out to a point, or to a fingerlike projection on the sixth vein. The membranous lobe, called the calypter, on the thorax near the wing base, is small and inconspicuous, hence the name of the group, Acalyptratae. The foot (the terminal part of each last tarsal joint) does not have the central structure (the empodium) developed into a pad, and thus the empodium is stated to be not "pulvilliform" (i.e., not resembling the two other padlike structures (the pulvilli), one of which is near each claw. The abdomen has only four well-defined segments in the male, exclusive of the genitalia, and five in the female exclusive of the ovipositor sheath; the ovipositor sheath is conspicuous, seldom shorter than the length of the preceding segment and usually very much longer; the ovipositor (or sting) is hard and sharp pointed, and is retractile.

The eggs are variable in size and shape as between species or groups of species. The larvae are maggots living in fruits, flowers, galls, the stems of plants, or in mines in the tissue of the leaves. They are essentially primary feeders, eating the growing tissue, and not acting as scavengers upon decaying organic matter. The larva is divided into segments. The head is a compound structure which looks like a single small segment, with no definite head capsule, the mouth provided with two black or blackish hooks with which the larva obtains food by means of raking motions. The anterior spiracles are located one on each side at the base of the first thoracic segment, usually called, to the exclusion of the head, the first segment. These spiracles are the modified ends of tracheae, and are divided into small tubules, usually called beads, which vary in number from 2 to more than 30 on each spiracle. The number of beads on a spiracle in any given species is often subject to much variation;

but, within limits, the number of such beads is of specific significance. Counting from the rear of the head, the three following segments constitute the thorax. The abdominal segments are not superficially defined from the thoracic segments and, therefore, the first abdominal segment is usually called the fourth segment.

There are eight visible abdominal segments; which, counting the thoracic segments as 1, 2, and 3, are usually numbered 4 to 11. The eleventh segment has the hind (caudal) end more or less modified, sometimes almost appearing to be two segments.[1] Two spiracles, the only developed larval spiracles aside from the anterior pair, are located on the rear end of this segment. Except in very young larvae there are three spiracular openings, usually called slits, on each spiracle. These slits remain reasonably constant in shape, size, and arrangement within any given instar of a single species, but furnish characters separating species or groups of species. The larval skin is clothed with minute spines which appear to be obsolescent or obsolete on parts of the segments of various species, but are often conspicuous, especially near the margins of the segments and on the under (ventral) side of many species. After completing feeding, the larva forms a puparium, which is simply a resting stage of the larva, and not a true pupa. Within this puparium another larval stage (instar) is passed before the true pupa is formed. This last larval stage is but little known, and when occasionally observed is usually mistaken for a case of parasitization. The emerging adult forces off the end of the puparium by the expansion of a bladderlike structure, called the ptilinum, which is extruded through the frontal suture. This is one of the fundamental characteristics which helps to define a very large group of Diptera, including all of the Acalyptratae.

## CHARACTERS USED IN CLASSIFICATION

An effort has been made to simplify the text. Nevertheless, certain terms are almost inescapable, especially the names of the different anatomical parts whose structure serves to supply differentiating characters. Definitions of the terms which are neither illustrated nor discussed under the heading Relationships and Structural Characters can be found in the larger dictionaries.

The terminology used for the various bristles, wing veins, and other structural parts is that recommended by J. M. Aldrich, associate curator of insects, United States National Museum

In preparing the illustrations for this publication no uniformity in the scale of magnification of the various parts has been possible. Figures 1 to 10 are intended to indicate the nomenclature used in discussing the many parts of any of the species, although one particular species may have been used for the outline. For the important dimensions of the various species discussed and figured the reader is referred to the respective descriptions in the text of this publication.

The names of the parts of the head, including the names of the bristles (chaetotaxy), are shown in figure 1.

Figure 2 shows the names of the parts of the thorax, including the names of the bristles (chaetotaxy).

The names applied to the parts of the wing, illustrating two different systems of terminology, are shown in figures 3 and 4. Figure 3

[1] The eleventh segment, the eighth abdominal, is a compound segment, presumably formed from the primitive eighth, ninth, and tenth abdominal segments.

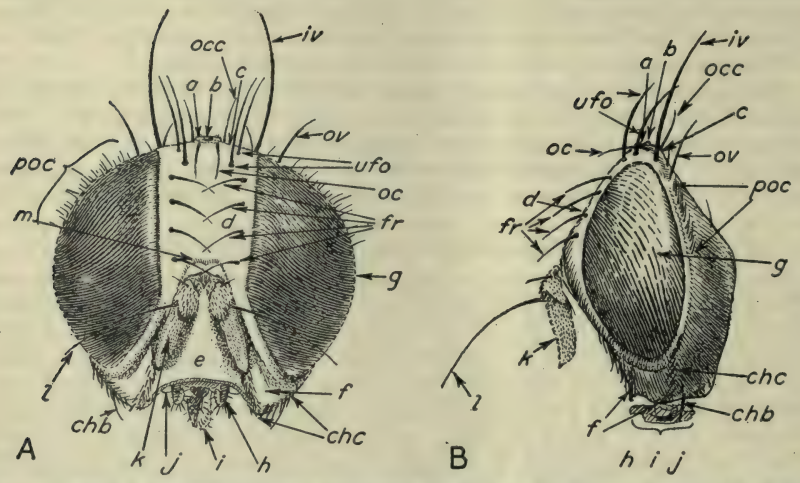


FIGURE 1.—Head of *Zonosemata electa:* *A*, Front view; *B*, side view; the parts are designated by the same italic letters in both views. *a*, Ocellar triangle; *b*, ocellus, two others not showing; *c*, vertex; *d*, front; *e*, face; *f*, cheek; *g*, compound eye; *h*, palpus; *i*, tongue, also called labellum or proboscis; *j*, mouth; *k*, antenna; *l*, arista (of the antenna); *m*, frontal suture; *occ*, occipital bristle; *iv*, inner vertical bristle; *ov*, outer vertical bristle; *ufo*, upper fronto-orbital bristles; *oc*, ocellar bristle; *fr*, frontal bristles; *poc*, postocular cilia; *chc*, cheek cilia; *chb*, cheek bristle.

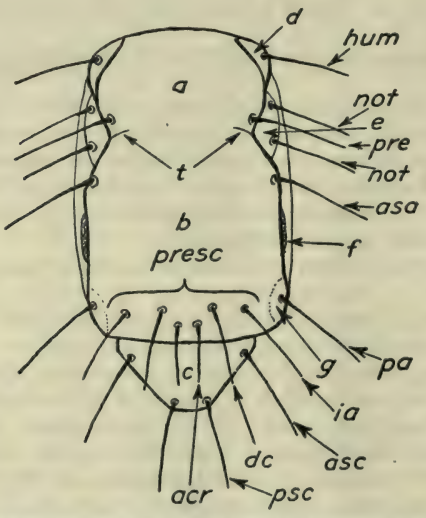


FIGURE 2.—Diagram of the dorsum (upper part) of the thorax of a species of *Anastrepha:* *a*, Prescutum of the mesothorax; *b*, scutum of the mesothorax (*a* plus *b* often called "the thoracic dorsum", or "the notum", or "the mesonotum"); *c*, scutellum; *d*, humerus; *e*, notopleuron or notopleura (in the plural also notopleura, or notopleurae); *f*, wing base; *g*, postalar callus (poorly defined, or invisible); *t*, the suture (the transverse suture, but usually called the suture); *hum*, humeral bristle; *not*, notopleural bristles; *pre*, presutural bristle; *asa*, anterior supraalar bristle; *pa*, postalar bristle; *ia*, intraalar bristle; *dc*, dorsocentral bristle; *acr*, acrostichal bristle; *asc*, anterior scutellar bristle; *psc*, posterior scutellar bristle; *presc*, prescutellar row of bristles.

gives the names as used most extensively, and these are the names used in this publication. Figure 4 shows the names of the same parts as used in the Comstock-Needham system.

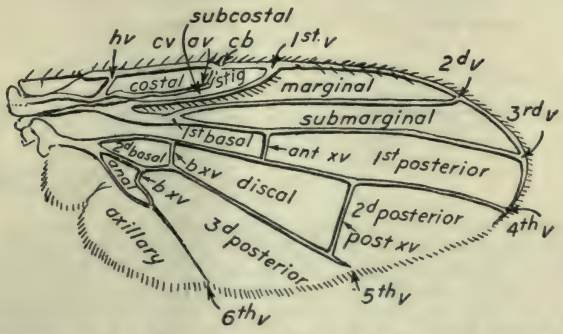


FIGURE 3.—Diagrammatic drawing of the upper side of the wing of *Rhagoletis cingulata*, with the names of the cells and the veins in general use by students of Diptera: *hv*, Humeral cross vein; *cv*, costal vein or costa; *av*, auxiliary vein; *1st v*, first (longitudinal) vein; *2d v*, second (longitudinal) vein; *3d v*, third (longitudinal) vein; *4th v*, fourth (longitudinal) vein; *5th v*, fifth (longitudinal) vein; *6th v*, sixth (longitudinal) vein; *antxv*, anterior cross vein; *postxv*, posterior cross vein; *bxv*, basal cross vein; *cb*, costal break; *costal*, costal cell; *subcostal*, subcostal cell; *stig*, stigma; *marginal*, marginal cell; *submarginal*, submarginal cell; *1st posterior*, first posterior cell; *2d posterior*, second posterior cell: *3d posterior*, third posterior cell; *axillary*, axillary cell; *1st basal*, first basal cell; *2d basal*, second basal cell; *anal*, anal cell.

The names applied to the parts of the abdomen and the male genitalia are given in figures 5 and 6. The genitalia are usually folded beneath the abdomen so the first genital segment is mostly hidden,

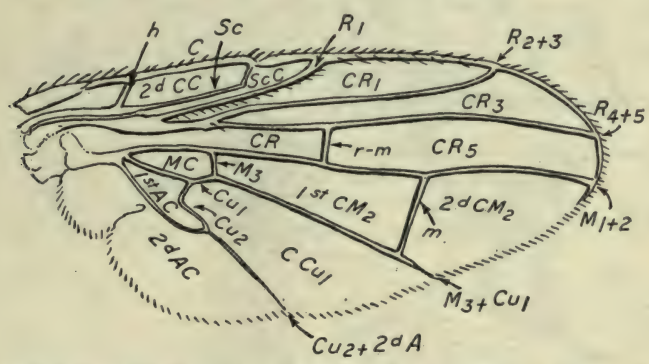


FIGURE 4.—Diagrammatic drawing of the upper side of the wing of *Rhagoletis cingulata*, with the names of the cells and the veins, according to the Comstock-Needham system: *h*, Humeral cross vein; *C*, costal vein, or costa; *Sc*, subcostal vein; $R_1$, (vein) radius 1; $R_{2+3}$, (vein) radius 2 plus 3; $R_{4+5}$, (vein) radius 4 plus 5; $M_{1+2}$, (vein) media 1 plus 2; $M_{3+}Cu_1$, (vein) media 3 plus cubitus 1; $Cu_{2+}2dA$, (vein) cubitus 2 plus second anal; *r-m*, radio-medial cross vein; *m*, medial cross vein; *2d C C*, second costal cell; *Sc C*, subcostal cell; *C* $R_1$, cell radius 1; *C* $R_3$, cell radius 3; *C* $R_5$, cell radius 5; *2d C* $M_2$, the second media 2 cell; *C* $Cu_1$, cell cubitus 1; *2d A C*, second anal cell (the cell formed by the second anal vein); *C R*, the radial cell; *1st C* $M_2$, first cell media 2; *M C*, medial cell (the cell below the unbranched part of vein media, hence, the medial cell); *1st A C*, first anal cell.

but often it overlaps a part of the ring of the second genital segment; and because of the folding the distal (tip) ends of the forceps are usually directed toward the thorax or toward the legs.

Figure 7 shows the names applied to the parts of the female genitalia.

The names applied to the parts of the larva (or maggot) are shown in figure 8, and the anterior spiracle is shown more in detail in figure 9.

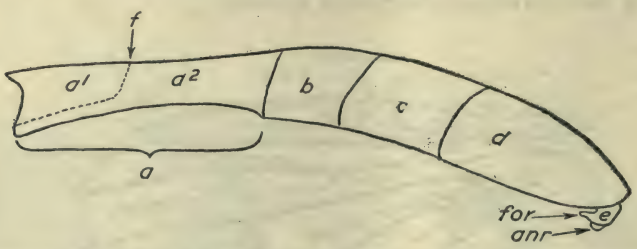


FIGURE 5.—Diagrammatic side view of the male abdomen of *Toxotrypana curvicauda*. Aside from the genitalia, only the upper plates (tergites) are visible, the lower (ventral) plates (sternites) being hidden: *a*, Usually called the first abdominal segment (in reality only the tergites of the first and of the second segments); $a^1$, the so-called proximal part of the first segment (in reality the tergite of the first abdominal segment); $a^2$, a part of the so-called first abdominal segment (in reality the tergite of the second segment); *b*, the so-called second abdominal segment (in reality the tergite of the third segment); *c*, the so-called third abdominal segment (in reality the tergite of the fourth segment); *d*, the so-called fourth abdominal segment (in reality the tergite of the fifth segment); *e*, male genitalia; *anr*, anal region; *for*, forceps; *f*, obsolescent division between the first and second tergites.

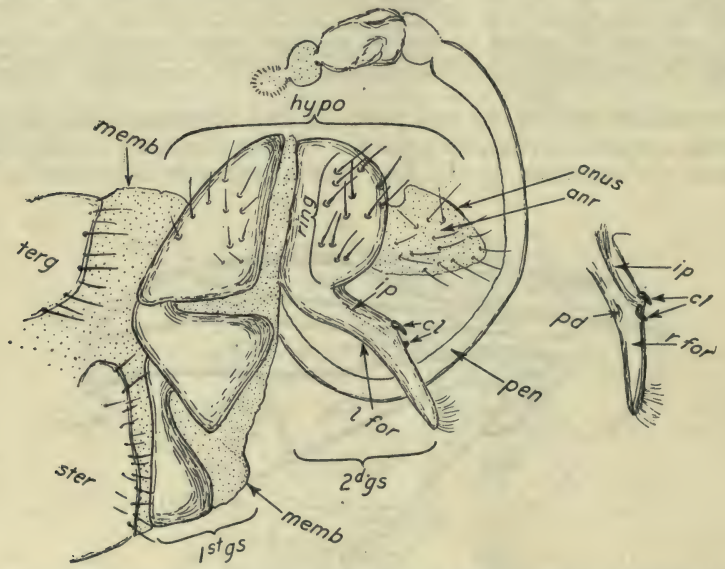


FIGURE 6.—Side view of caudal part of abdomen of *Rhagoletis cingulata*, showing the male genitalia, with a detached drawing of the inside of the right half of the forceps: *terg*, Tergite of the fourth (in reality the fifth) abdominal segment; *ster*, sternite of the fourth (fifth) abdominal segment; *1st gs*, first genital segment (in reality a modification of primitive segments 6, 7, and 8); *2d gs*, second genital segment; *ring*, the upper or ring-shaped part of the second genital segment; *l for*, the left half of the forceps, or left clasper; *r for*, the right half of the forceps, or right clasper, showing the structures of the inner part; *pd*, pad (a small soft structure, presumably sensory); *ip*, inner process (one on the inner side of each half of the forceps); *cl*, claws, or heavy spines; *pen*, penis; *anr*, anal region, or anal elevation (soft and distensible in life); *anus*, anus, or rectum; *hypo*, hypopygium (the visible structures of genitalia exclusive of the penis); *memb*, membrane connecting the various sclerites and the segments, a part of the body wall. Figured from microscopical preparations.

The caudal end of *Zonosemata electa* is shown in figure 10 with the names of the various structures indicated.

## ECONOMIC IMPORTANCE OF THE GROUP

The trypetids, because their larvae begin feeding on growing or normal plant tissues, include many species which are serious economic pests. Of the species native to the United States, most of those

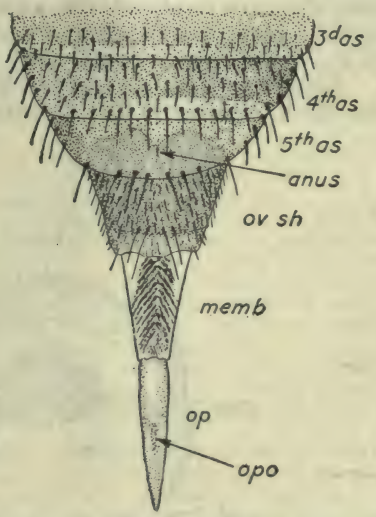


FIGURE 7.—Dorsal view of caudal part of abdomen of a female of *Rhagoletis cingulata*, as seen on a microscope slide. *3d as*, Third (in reality the fourth) abdominal segment; *4th as*, fourth (fifth) abdominal segment; *5th as*, fifth (sixth) abdominal segment; *ov sh*, ovipositor sheath (frequently called the ovipositor in various publications); *memb*, membranous part (more or less equipped with chitinized platelets usually arranged in inverted V-like rows, these platelets specifically modified into rectangular plates, spines, or clawlike structures); *op*, ovipositor (or sting); *opo*, ovipositor opening (for the eggs) on the under side; *anus*, anus or anal opening, the opening of the alimentary canal, on the underside.

belonging to the genus *Rhagoletis*, including the apple maggot, the cherry maggots, and the walnut husk maggots, are in the latter category. One native species, the pepper maggot, *Zonosemata electa*, is recorded as causing serious loss to pepper growers in New Jersey.

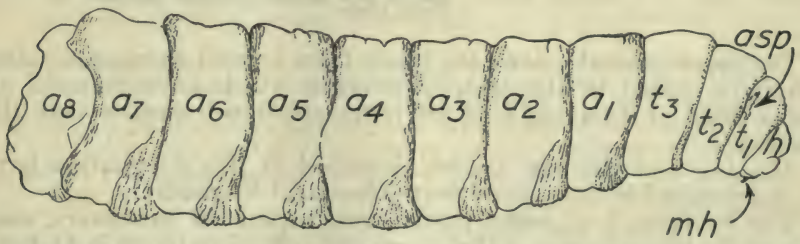


FIGURE 8.—Diagrammatic side view of the larva of *Zonosemata electa*: *h*, Head (more than a single segment); $t_1$, first segment (first thoracic); $t_2$, second segment (second thoracic); $t_3$, third segment (third thoracic); $a_1$, fourth segment (first abdominal); $a_2$, fifth segment; $a_3$, sixth segment; $a_4$, seventh segment; $a_5$, eighth segment; $a_6$, ninth segment; $a_7$, tenth segment; $a_8$, eleventh segment (eighth abdominal); *mh*, mouth hooks; *asp*, anterior spiracle.

The papaya fruit fly, *Toxotrypana curvicauda*, which is now rather abundant in Florida, was probably introduced with papayas. A number of foreign species have been considered as ranking among the most serious of the insect pests of agriculture.

## KEY TO THE GENERA AND SUBGENERA FOUND IN FLORIDA

The specific descriptions should be read in conjunction with the generic descriptions, as the characters cited under the generic names are not repeated under the specific names. The figures should be consulted when reading the descriptive text, as they illustrate the shapes and positions of the various structures, and, in part, the markings. In comparing the figures allowance must be made for the fact that these were drawn by various artists, each with a somewhat different technique. The drawings were made by Ezekiel Rivnay, Donald T. Ries, Mrs. E. A. Carlin, W. N. Dovener, and Mrs. E. B. Fitzgerald.

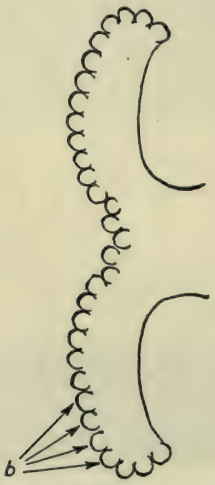


FIGURE 9.—Lateral view of the anterior spiracle of *Zonosemata electa: b*, Beads.

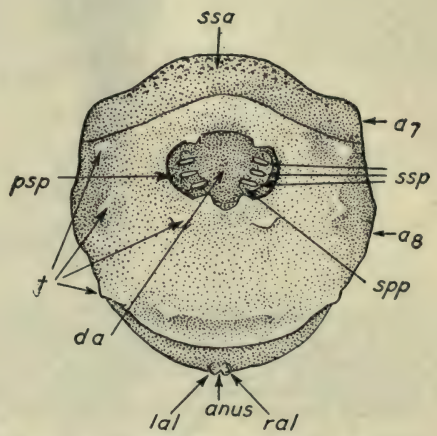


FIGURE 10.—Diagrammatic view of the rear end of a larva of *Zonosemata electa:* $a_7$, Tenth segment (seventh abdominal); $a_8$, eleventh segment (eighth abdominal); *ssa*, spinose skin area; *da*, depressed area (obsolescent in many species); *psp*, posterior spiracle; *spp*, posterior spiracular plate; *ssp*, posterior spiracular slits; *t*, tubercles; *anus*, anus (rectum, or anal opening); *ral*, right anal lobe; *lal*, left anal lobe.

The measurements given are taken from normal specimens unless otherwise stated in the text. Specimens which have matured on either dried or decaying food are frequently much smaller than the normal.

The types of the new species described in this publication have been deposited in the United States National Museum.

The following key, based partly upon superficial characters, may help in the identification of the genera and subgenera found in Florida:

1. All head bristles short, the frontals, the orbitals, and the ocellars present but obsolescent and so weak that they are often broken and lost **Toxotrypana.**

   At least some of the head bristles, including the frontals, strong and well defined ..... **2.**

2. Wing design never either reticulate or spotted; anal cell usually drawn out long and fingerlike to a point in the sixth vein, occasionally the pointed part moderate in length but never short; two pairs of strong upper orbital bristles; the dorso-central bristles in, or behind, the line of the anterior supraalars and not near the transverse suture ..... 3.

Frequently the wing has either a reticulate design or many hyaline or pale and rounded spots interrupting the dark part of the pattern; either the anal cell has only a short projection on the sixth vein, or at least 1 of the 2 pairs of upper orbital bristles modified to scalelike bristles, or one or both pairs of the upper orbital bristles absent; or the dorso-central bristles close to the transverse suture and well in front of the line of the anterior supraalars ..... 5.

3. Third vein unspined, or spined only on the knot at the junction with the second vein ..... **Rhagoletis.**

Third vein spined distad of the knot at the junction with the second vein. 4.

4. Third antennal segment with a spinelike tip ..... **Zonosemata.**

Third antennal segment rounded at the tip ..... **Myoleja.**

5. Frequently only a single pair of upper orbital bristles present; costa of wing normal; the scutellum swollen, globose, and polished. **Procecidochares.**

Usually with a single pair of strong upper orbital bristles and a second pair of pale scalelike upper orbital bristles, or with two pairs of strong upper orbitals, or the upper orbitals absent; if only a single pair of upper orbitals present the costa of the wing distorted; scutellum seldom swollen, never globose, and polished ..... 6.

6. Vertex of the head at least twice as broad as the maximum width of 1 eye; third vein spined but the spines difficult to see; with at least 1 pair of upper orbital bristles; third antennal segment broad and more or less lobate ..... 7.

Vertex of the head not twice as broad as the maximum width of one eye, the character only approximated in a single genus which has the third joint of the antennae elongated and pointed ..... 8.

7. The black bristles of the head and thorax from conspicuous rounded black spots; usually with only a single pair of upper orbital bristles; wing with the costal margin distorted, the pattern consisting of oblique dark bandings usually joined near the costa, and with no trace of reticulation ..... **Peronyma.**

The bristles of the head and thorax not from conspicuous rounded black spots; 2 pairs of upper orbital bristles, 1 pair frequently pale and scalelike; wing with the costal margin normal, and with a dark design obscuring most of the ground but broken by hyaline and semihyaline incisions and droplets which create a more or less reticulated appearance **Eurosta.**

8. Frontal bristles erect and scarcely converging; 3 pairs of long pale erect bristles inside of the frontals between the middle of the front and the vertex, possibly being the upper orbital bristles which are otherwise absent; head marked with conspicuous and contrasting black spots **Paracantha.**

Frontal bristles always converging, and usually strongly so; no long pale erect bristles inside of the frontals between the middle of the front and the vertex; 2 pairs of upper orbitals, 1 pair frequently scalelike ..... 9.

9. Two pairs of strong upper orbital bristles of similar texture; third vein with at least several bristles distad of the stalk of the second vein; abdomen with conspicuous lateral or dorsolateral black spots ..... 10.

Usually with 1 pair of the 2 pairs of orbital bristles scalelike; or if both pairs appear relatively strong and subequal, the third vein naked, or the abdomen not possessing lateral or dorsolateral black spots ..... 11.

10. Wing design dark with hyaline rounded spottings; third antennal joint produced to a point ..... **Acidogona.**

Wing design consisting of oblique bandings on a hyaline ground; third antennal joint rounded at tip ..... **Tomoplagia.**

11. The upper pair of upper orbital bristles of the same texture as the lower pair, but nearly reclinate and conspicuously converging; third vein naked; wing, excepting the stigma, often entirely hyaline; usually with a polished and disconcolorous black spot on the thorax in back of the occiput **Neaspilota.**

The upper pair of upper orbital bristles usually differentiated from the lower pair by being pale and scalelike, and never definitely converging; third vein naked or spined; wing, excepting the stigma, never entirely hyaline ..... 12.

12. Head as long (front to rear) as high, and the proboscis very long, slim, and folded ..... **Paroxyna.**
Head seldom as long as high; the proboscis not long, slim, and folded .. 13.

13. Vertex of head conspicuously narrower than the maximum width of 1 eye; wing with a design interrupted by hyaline incisions only along the costal and the posterior margins, and with only 2 or 3 rounded hyaline spots or droplets on the disk ..... **Xanthaciura.**
Vertex of head subequal to, or broader than, the maximum width of 1 eye; wing usually with more than 2 or 3 rounded hyaline spots on the disk, or with either a reticulate or a stellate pattern ..... 14.

14. Inner and outer vertical bristles brown and of the same texture, although the former are much longer than the latter; with at least 3 pairs of frontal bristles ..... **Acinia.**
Outer vertical bristles paler and more scalelike than the inner verticals; the only genus likely to cause confusion, because of the generally pale coloration of all of the head bristles; possesses only 2 pairs of frontals .. 15.

15. Second male genital segment much enlarged, and distally bearing several oblique ridges on each side of the anal region; no stellate subapical marking on the wing, the pattern formed of dark markings interrupted by hyaline spots and droplets; only 2 pairs of frontal bristles ..... 16.
Second male genital segment not conspicuously enlarged and not distally bearing several oblique ridges on each side of the anal region; wing either with a stellate subapical marking, or, if the pattern is formed of dark markings interrupted by hyaline spots and droplets, there is a pair of distinct but deciduous yellowish scalelike hairs below the 2 pairs of frontal bristles indicating a third pair of frontals ..... 17.

16. A strong callus in the first posterior cell; third vein with the spines weak and difficult to see; 2 or 3 spines well before the anterior cross vein and several similar spines distad of the cross vein .. **Euaresta** subgenus **Euaresta.**
No callus in the first posterior cell; third vein distinctly bristled
**Euaresta** subgenus **Setigeresta.**

17. Wing without a stellate subapical design, the pattern formed of dark markings interrupted by hyaline spots and droplets; third vein with at least 1 small deciduous spine near the knot at the junction of the second vein and with about 4 similar spines on that part of the third vein which is over the first posterior cell ..... **Dyseuaresta.**
Wing with a stellate subapical design, the proximal part either hyaline or reticulate; third vein naked ..... **Trupanea** 18.

18. Three pairs of frontal bristles, the lowest pair much reduced in length; scutellum with a single pair of bristles; base of wing hyaline, lacking reticulations ..... **Trupanea** subgenus **Trupanea.**
Either 3 subequal pairs of frontal bristles or only 2 pairs; scutellum with 2 pairs of bristles; base of the wing reticulate ..... 19.

19. Three pairs of subequal frontal bristles .. **Trupanea** subgenus **Euarestoides.**
Two pairs of frontal bristles ..... **Trupanea** subgenus **Tephritoides.**

## THE GENUS TOXOTRYPANA GERSTAECKER

*Adult.*—Head flattened; vertex somewhat broader than maximum width of eye; the latter, while appearing elongate and narrow, so curved that it occupies part of the back of the head; frons sunken below vertex, produced as a peaked ridge over the antennae; third antennal joint elongate, narrow; the normal frontal bristles reduced, but neither pale nor scalelike; obsolescent or nearly so; practically lost in the scattered fine cilia which clothe the front and which are especially noticeable near the eyes; 3 pairs of these much reduced frontal bristles recognizable, occasionally a fourth pair; 1 pair of similarly reduced upper orbitals; 1 pair of similarly reduced ocellar bristles; occipitals very weak, but relatively long; inner and outer pairs of verticals short, but the strongest and best defined bristles of the head; the former strongly convergent, the latter strongly divergent; postocular cilia long and dark, but very fine and inconspicuous; cheek bristle not differentiated from the relatively long cheek cilia. Thoracic dorsum clothed with fine, glistening, brownish or pale hairs; the bristles more or less deciduous, thin, short, brownish, and inconspicuous; humeral pair of bristles absent or indistinguishable from vestiture; presutural pair almost indistinguishable; acrostichals absent; postalars,

intraalars, and dorsocentrals short and weak, but easily recognizable; scutellum with 1 pair of short apical bristles. Abdomen long and slender, clothed with a mixed vestiture of glistening pale and black hairs; basal segment long, clearly showing that it is composed of 2 fused segments; remaining abdominal segments, in the male, equal in length to the basal segment; subequal in the female because of the reduction and specialization of the last ordinary segment; last abdominal segment of the male as long as the 2 preceding segments, thus differing radically from the segment preceding the ovipositor sheath of the female; ovipositor sheath clothed with glistening brownish or blackish hairs, thin, but, while greatly variable in length, always exceeding total length of remainder of abdomen together with thorax and head. Male genitalia relatively small, the forceps narrowed and curved toward each other; internal process large and bearing 2 strong claws; penis of a length comparable with that of the ovipositor sheath of the female. Wing long and narrow; first vein spined; second vein irregular in its course, sexually dimorphic as illustrated; third vein with fine spines to well beyond the short, anterior cross vein; fourth vein much bent and waved in its course; posterior cross vein oblique; discal cell long and narrow, nearly attaining posterior margin; anal cell with tip drawn out to a long point on the sixth vein.

Type of the genus, *Toxotrypana curvicauda* Gerstaecker.

The generic name was proposed by Gerstaecker (*29, p. 191*)[2] in 1860, with *curvicauda* the sole species, and therefore the genotype. In 1884 Bigot (*9, p. xxix*) proposed the genus *Mikimyia*, with *furcifera* n.sp. sole species, and therefore genotype. The genotypes are conspecific and hence the two genera are synonymous. Some of the early workers were inclined to place the genus with the ortalids, while others suggested the trypetids. See Loew (*60, pp. 27, 34, 36*), Osten-Sacken (*66, p. 181*), Bigot (*10, p. 292*), Roeder (*71, p. 31*), and Snow (*84, p. 117*). Since the paper by Snow in 1895 the genus, which contains only a single known species, has been consistently retained with the trypetids.

### TOXOTRYPANA CURVICAUDA Gerstaecker

(Fig. 11, *A–Q*)

*Toxotrypana curvicauda* was described by Gerstaecker (*29, p. 194*) in 1860. Subsequently it was described by Bigot (*9, p. xxix*) in 1884 as *Mikimyia furcifera*. Many authors have discussed the species because of its economic significance. The earlier references are indicated under the generic description. Most of the later references are easily available from the various indexes of economic entomology.

*Adult.*—Head, including the antennae, luteous, appearing more or less to be tinted with rufous brown on specimens which have aged. Thorax with the ground color lemon yellow, sometimes apparently sordid white or brownish on specimens which have aged, and marked with black and fuscous brown as shown in figure 11, *k*; scutellum concolorous with the thorax and likewise marked with fuscous brown and black on the proximal and lateral margins. Legs concolorous with the thorax, the hind femora and coxae more or less marked with fuscous brown and black. Abdomen with the lemon yellow ground color much obscured by brown, the ovipositor sheath appearing quite brownish. Wing hyaline, marked by luteous brown darkest toward the costa. Size: Variable; wings of normal males range from 7 to 10 mm in length and from 2.5 to 3.5 mm in width, of female 10 to 11 mm in length and 3.25 to 3.5 mm in width. Length of male 9.5 to 12.5 mm, of female 22 to 25 mm; abdomen and ovipositor so curved that a measurement following the curvature is from 4 to 7 mm longer.

*Immature stages.*—Eggs white, elongate. Larva white, large, the largest measuring about 14 mm in length and somewhat over 3 mm in diameter; segments clearly defined; skin, although appearing smooth, finely and densely stippled with minute spines which tend, near the segmental sutures, to be arranged in irregular rows; anterior spiracles asymmetrical in shape and with about 18 to 22 beads, usually in a single line, abnormally 1 or 2 beads out of alignment; posterior

[2] Italic numbers in parentheses refer to Literature Cited, p. 91.

spiracles large, relatively close together, the slits elongate, with subparallel sides, those on each spiracle nearly subparallel. Puparium brownish to dark rufous brown, the segmental lines distinct; measuring from about 8 to 9.5 mm in length and from 3.5 to 4 mm in diameter.

*Host.*—The female lays the eggs within the seed cavity in the fruits of papaya, *Carica papaya*, where the larvae normally feed.

*Distribution.*—Specimens were submitted for identification from over 60 different localities in Florida, and the species is probably quite generally distributed and abundant wherever its host is found in the southern half of the State, becoming scarce northward. The author has seen a single specimen caught in the Rio Grande Valley in Texas. The species is recorded from as far north as South Carolina (*36, p. 10*), and has been reported from many of the West Indian Islands, and from Mexico southward to Brazil and Peru.

## THE GENUS RHAGOLETIS LOEW

*Adult.*—Head relatively broad, vertex narrower than maximum width of eye, frons scarcely tapered in width but distally somewhat produced; third antennal joint pointed; arista somewhat pubescent; head bristles all black or blackish except occipitals and cheek bristles and cilia; three pairs of long frontal bristles; two pairs of upper orbitals; one pair of long ocellar bristles; inner and outer verticals strong; occipitals weak, pale, short, and practically parallel; postocular cilia relatively strong, typically black or blackish; cheek bristle pale but strong; cheek cilia either pale or dark near the mouth, elsewhere pale; frons more or less clothed with short, sparse, brownish or dark hair. Thoracic dorsum clothed with short, fine cilia which are more or less concolorous with the parts from which they arise; normal bristles strong and black; dorsocentrals approximately in line with anterior supraalars but not close to the suture; acrostichals, intraalars, and postalars forming a transverse and almost straight prescutellar row; scutellum with two pairs of long black bristles. Abdomen, exclusive of the short and broad ovipositor sheath, subequal in length with the thorax, clothed with fine hair which approximates the coloration of the parts from which it arises, and with longer and dark bristly hair from the apices and the sides of the terminal segments. Male forceps conspicuously narrower than dorsal part of second genital segment, relatively flat and not incurved toward each other, internal process with two strong claws, anal region moderately large. Wing with first vein strongly bristled, third vein naked in the *pomonella* group, or with one or two bristles on knot at junction of second and third veins in the *cingulata* and *juglandis* groups; anterior cross vein near middle of discal cell, the latter relatively long and closely approaching posterior margin; anal cell produced on sixth vein to a moderate, or a long, point.

Type of the genus, *Musca cerasi* Linnaeus.

Many of the included species tend to form host strains and local colonies separable by slight differences in the amount of pollinose marking on the thorax, by the amount of brown marking which obscures the yellow of the legs, and by slight differences in the extensions and depth of coloration of the dark markings of the wings, so that from a small series of individuals, or from individuals selected from separate colonies, various supposed "species" might be selected. These differences appear to intergrade completely upon examination of sufficient material. Nevertheless some of the species are very closely allied, and, in the opinion of the author, the revision of the genus by Cresson (*17*) lumps too extensively. A recent paper by Curran (*21, pp. 3–8*) places too much stress on the exact shape of the broader end of the "sustentacular", or ejaculatory, apodeme of the male genitalia as a means of sorting closely related species. This is quite a variable structure, at least in *Rhagoletis*. The presence or absence of bristly hair tuftings on the forceps, and the shapes of the forceps

and of the second male genital segment, together with the nature of the hair on the latter, seem to be good specific characters.

The generic name was first proposed by Loew (*59, p. 44*) with *Musca cerasi* Linnaeus, and included synonyms, as the sole species. Coquillett (*14, p. 599*), in 1910, designated the genotype, *Musca cerasi* Linnaeus. Herrera, assisted by other authors, began a series of papers in 1901 in which the prefix *Ins* was consistently added to all insect generic names utilized in these papers. This treatment was accorded the generic names *Rhagoletis* (*39, p. 410; 40, pp. 148, 153; 39, p. 410*) and *Ortalis* (*39, p. 411*), the former in connection with *pomonella* Walsh and ?*cingulata* Loew, and the latter in connection with *cerasi* Linnaeus. These emendations have been ruled as zoological formulae, and hence unavailable as generic names (*80, pp. 19–22*). Aside from this deviation the name *Rhagoletis* has been used rather consistently from 1862 to the present time for all species herein discussed under that name. Occasionally, since 1862, authors have used the generic name *Trypeta*, but usually followed by the name *Rhagoletis* in a subgeneric capacity.

*Rhagoletis* is very closely related to *Zonosema*, which may ultimately have to assume subgeneric status, the essential differences being that *Rhagoletis* possesses a somewhat less globular head, has the spining on the third vein absent, or reduced to one or two spines on the knob at the junction of the second and third veins, and usually has a somewhat different wing shape and habitus. The species feeding as larvae within the husks of nuts are somewhat intermediate between the two genera, yet of themselves form a rather specialized group.

#### RHAGOLETIS CINGULATA (Loew)

(Fig. 12, *A–L*)

Described as *Trypeta cingulata* (*57 p. 76*) by Loew. The larva is often called the cherry maggot; and the adult, the cherry fruit fly. The species, a well-known pest of cherries, has been discussed by many authors. Either this species or the related *R. fausta* Osten-Sacken was recorded as early as 1835 (*33, p. 80*) by Harris under the generic name *Ortalis*, and confused with the corresponding European species, *cerasi* Linnaeus. Illingworth (*42*), in 1912, published on the biology, also giving citations to most of the more important bibliographical references to that date. Curran (*21, p. 8*), in 1932, redescribed the species as *Rhagoletis indifferens* based on specimens from Oregon reared from wild cherry, *Prunus marginata*. The character of the wide ejaculatory apodeme does not hold in slides made by the writer, this structure being quite variable in width, even in material reared from a single host in Florida.

*Adult.*—Head yellowish with a rufous cast, disconcolorously paler near eyes and mouth and beneath antennae. Thorax dark brown dorsally, somewhat paler laterally and ventrally; with a broad, somewhat divided, irregular, longitudinal, pollinose, whitish stripe on each side of center of dorsum excepting caudal half of mesoscutum, the two stripes almost joined mesially, and causing dorsum of thorax to appear very largely covered with pollinose white; humerus white and connected by a white lateral stripe with wing base; scutellum dark brown with a large dorsoapical white spot in which the posterior, and sometimes the anterior, pair of bristles are situated. Legs yellowish, more or less tinged with brown. Abdomen dorsally dark brown with white crossbands on the posterior margins of first three segments in male and first four segments in female. Male forceps relatively narrow, and with a conspicuous apical tuft of bristly hair. Wing

hyaline; marked by a fuscous brown pattern as illustrated in figure 12, *G*; the dark apical spot often touching the dark inverted V. Size: Variable, more or less in proportion to the size and quality of the host. Specimens from cultivated cherries, wild tea-olives, and fringetree fruits averaging larger than those from the smaller wild cherries. Specimens from wild cherry measure: Male wing 3.6 by 1.55 mm, female wing 3.8 by 1.7 mm; length of male 3.6 mm, of female 4 mm. Specimens from the larger host fruits measure: Male wing 4 by 1.8 mm, female wing 4.5 by 2.2 mm; length of male 4 mm, of female 4.6 mm.

*Immature stages.*—These have been fully described by many authors, and the reader is referred to the paper by Illingworth (*42*) for more detailed description. The larva is white, elongate, the segmental sutures usually constricted, causing a roughened appearance which is further exaggerated by lateral swellings and ridges; the skin possesses minute spines arranged in irregular transverse rows near the segmental lines on all segments, except the first, and obsolescent on that segment; the anterior spiracles vary in the number of beads but usually each possesses from 12 to 15, arranged more or less in a row, with an irregular secondary row of beads varying in number and tending to parallel the distal row; the posterior spiracles are relatively close together, the slits elongate with the sides more or less nearly parallel, each spiracle with the median slit tending to be bent so that the outer end is subparallel with the slit nearest the dorsum and the mesial end subparallel with the slit nearest the venter; the caudal end of the eleventh segment is strongly tuberculate in the manner illustrated. The puparium is straw to brownish in color, and the segmental sutures are easily seen. The larvae and the puparia vary greatly in size, depending upon the kind and quality of the host, fully matured larvae ranging from about 5.5 to over 7 mm in length, and from 1.1 to 2.1 mm in diameter. The puparia range from less than 3 to nearly 4 mm in length and from about 1.5 to 2.3 mm in diameter.

*Hosts.*—Adults were bred from larvae from the fruits of wild cherry (*Prunus serotina*), of fringetree (*Chionanthus virginica*), and of wild tea-olive (*Osmanthus americana*). The larvae are a well known pest of cultivated cherries. This host is, however, not present in the parts of Florida which were inspected.

*Distribution.*—New England to Georgia and Florida, and westward to Oregon; not as yet recorded from most of the Southern States or from any of the Southwestern States.

### RHAGOLETIS POMONELLA (Walsh)

(Fig. 13, *A–L*)

The larva is often called the apple maggot or the railroad worm. The species was described as *Trypeta pomonella* by Walsh (*93, pp. 338–343*) in 1867, although usually credited to Walsh (*94, pp. 29–33*) as of 1868. It was discussed, without the proposal of a scientific name, in 1866, by Walsh (*92, pp. 20–21*) as a pest of apple, and had previously received some comment in local periodicals in New York State. Glover (*30, pp. 72–73*) discussed the species under the Walsh name. It was again mentioned by Walsh and Riley (*95, p. 59*) in 1868, and by 1869 had become so well known that it was discussed by Packard (*67, p. 415*) in a textbook on entomology. Since then the species has been repeatedly discussed by many authors in publications ranging from newspapers and magazines to bulletins. Illingworth's paper (*41*) in 1912 on the biology also contains summaries of the most important bibliographical references to that date. Snodgrass (*81*) has published an extensive paper on the anatomy of the larva. The name *albiscutellata*, appended by Say to a specimen now in the collections of the Boston Society of Natural History, was listed in 1835 (*33, p. 80*), in 1858 (*65, p. 78*), in 1862 (*57, p. 57*), and in 1873 (*60, p. 335*), but remained a nomen nudum until published by Johnson

(*54, p. 97*) in 1925. The author has examined the specimen and agrees with Johnson that it is a specimen of *pomonella*.

The recently described *Rhagoletis mendax* Curran (*21, p. 7*) has been omitted from consideration under *R. pomonella*. This name is applicable to the blueberry maggot and its adult.

*Adult.*—Head yellowish, with a rufous cast, disconcolorously paler near eyes and mouth and beneath antennae. Thorax dark brown to blackish brown, somewhat paler beneath; with a broad, somewhat divided, irregular, longitudinal, pollinose whitish stripe on each side of center of dorsum, excepting caudal end of mesoscutum; humerus white and connected by a white lateral stripe with wing base; scutellum dark brown, concolorous with thorax, with a large dorsoapical white spot not extending onto the lateral margins, the anterior bristles on the dark ground, the posterior pair on the edge of the white. Legs yellowish, the femora variable in coloration, but usually more or less tinged with brown. Abdomen dorsally dark brown with white crossbands on posterior margins of first three segments in male and of first four segments in female. Male forceps with edges evenly curved and subparallel. Wing hyaline; marked by a fuscous brown pattern as illustrated in figure 13, *G*; the hyaline triangle which invades the discal cell seldom, if ever, reaching the fourth vein. Size: Male wing 3.8 by 1.8 mm, female wing 4.2 by 2 mm. Length of male 4.25 mm, of female 4.6 mm.

These measurements apply as an average to series, exclusive of underdeveloped specimens, reared from *Crataegus*. The available specimens from apple do not differ conspicuously in size. Specimens reared from the fruits of dogwood are somewhat smaller. Those reared from wild plums are mostly somewhat smaller than those reared from dogwood, but this may be due to the food being inferior after the infested plums were gathered from the trees, as a number of specimens which emerged from puparia sifted out of the soil from beneath trees bearing infested plums closely approximate specimens reared from *Crataegus*.

*Immature stages.*—These have been fully described by many authors. The reader is referred to papers by Snodgrass (*81*) and by Illingworth (*41*) for more detailed description.

Larva white, elongate, about 5.5 to 7 mm in length and 1.5 to 1.6 mm in diameter, smooth in appearance, but possessing minute spines arranged in irregular transverse rows near the segmental lines on all segments, except the first. The anterior spiracles vary greatly in their exact shape and number of beads, but usually each possesses more than 20 beads, which are arranged in the peculiar manner shown in figure 13, *B*; posterior spiracles relatively close together, the slits elongate with approximately parallel sides, each spiracle with the two slits nearest the dorsum subparallel, the one nearest the venter more oblique; caudal end of eleventh segment strongly tuberculate as shown in figure 13, *A* and *C*. Puparium pale straw to brownish in color, with the segmental sutures defined but inconspicuous, from about 4 to 5.6 mm in length and 2 to 2.3 mm in diameter.

*Hosts.*—Adults were reared from larvae from the fruits of apple, of hawthorn (*Crataegus*), of dogwood (*Cornus florida*), of wild plums (*Prunus umbellata* and *P. angustifolia*), and of chokeberry (*Aronia arbutifolia*).

*Distribution.*—Only locally common in Florida, and apparently restricted to the northern half of the State. Recorded from Canada to Florida and westward, the extreme western records needing verification because of the general confusion of this species with the closely related *R. zephyria* Snow (*symphoricarpi* Curran). The author has seen larvae, which were presumably this species, from haws intercepted at the Mexican border as being of Mexican origin.

### RHAGOLETIS ZEPHYRIA Snow

(Fig. 14, *A–L*)

Described as *Rhagoletis zephyria* (*83, p. 164*) by Snow in 1894. Doane (*24, p. 69*) questioned the validity of the species, and Aldrich (*3, p. 69*) and Treherne (*89, p. 329*) did not distinguish the species from *pomonella*. Curran (*18, p. 57; 19, pp. 62–63*) differentiated the species on the basis of examination of a so-called type female, and cited colorational characters to separate it from a series of specimens described as a new species under the name *R. symphoricarpi*. The type series of the latter are stated to have been reared from the fruit of the snowberry, *Symphoricarpus racemosus*, from localities in western British Columbia. Snow described *zephyria* from five specimens stated to have come from southern California and to be males. A male reputed to be one of these types and bearing a type label is in the Johnson collection at the Museum of Comparative Zoology. The genitalia have been examined by the author and appear identical with those of specimens bred from *Symphoricarpus*, from Victoria, British Columbia, and from Corvallis, Oreg. The aforementioned type specimen also appears to the author to be indistinguishable in coloration from some of the specimens in the reared series of *symphoricarpi*, and accordingly the latter name is placed as a synonym.

*R. zephyria* has previously been recorded only from the West, mainly from the region of southwestern Canada and the northwestern part of the United States not far from the coast. It has been reported as monophagous, the fruits of *Symphoricarpus* being the only known host.

Nearly a hundred adult specimens of a species of the genus *Rhagoletis* were reared from various localities in the northern half of Florida. Large numbers of larvae of this species were submitted for identification from similar Florida localities by various members of the inspection forces, the species being abundant and generally distributed throughout the more northern half of the State wherever its host, the fruit of the sparkleberry (*Batodendron arboreum*), was found. Superficially, the adult specimens are variable to the same degree as those comprising the series of *zephyria* reared from snowberry. The only difference is that the average individuals of the Florida series have the white of the scutellum slightly more extended than the average individuals of the western series. Yet the extremes both of extension and of reduction of the white are similar. No differences were found in the genitalia although these structures furnish characters to separate both the Florida and the western series from the closely allied *R. pomonella* and *R. mendax*. From shorter series, or by the selection of individuals, or by obtaining individuals from single localities in the East and in the West, or by obtaining specimens which have been killed before full coloration was attained, two "species" may easily be sorted.

A separate name for the Florida series, based solely upon locality labels and host records, seems, at this stage, quite superfluous, especially in view of the monophagous tendency exhibited by each series in localities lacking the alternative host.

The following descriptions are based on the Florida series:

*Adult.*—Similar in all superficial details to *R. pomonella*, except averaging slightly smaller in size. Coloration variable, covering the same range as that of *pomonella*, but possibly averaging somewhat darker, the scutellum tending to

have the white spot smaller than proportionate to the reduced size so that the posterior bristles usually appear definitely surrounded by some black at their bases, and the legs tend to be more heavily tinged with brown and nearly concolorous with the ventral part of the thorax. Male forceps of a somewhat different shape from those of *pomonella*, the edges not being evenly curved and subparallel.

Both this species and *pomonella* vary individually to such an extent that the author would have considered the slight size and color differences of no especial significance were the genitalia identical. The genitalia were pointed out by Curran (*18*, *19*) as differentiating *R. symphoricarpi* from *R. pomonella*. Slides are usually unnecessary in order to see the character. However, a series of slides were made, and indicate it to be constant. *Size:* Male wing 3.0 by 1.5 mm, female wing 3.5 by 1.7 mm. Length of male 3.5 mm, of female 3.9 mm.

*Immature stages.*—Similar to those of *pomonella;* the larvae and puparia averaging somewhat smaller in size; and, usually, each anterior spiracle with 1 or 2 fewer beads, a matter of little significance.

The drawing of the anterior spiracle of *pomonella* (fig. 13, *B*) was made from a single spiracle, whereas that of *zephyria* (fig. 14, *B*) represents a composite made from several spiracles by careful selection. Scarcely any two anterior spiracles are identical in species of this group, usually differing somewhat on the two sides of the same larva. Nevertheless, the general pattern of the anterior spiracles in the *pomonella* group is radically different from that of the anterior spiracles of the *cingulata* group as may be visualized by a comparison of the figures. The fully matured larvae of *R. zephyria* seldom measure over 5 mm in length, and are about 1.2 to 1.3 mm in diameter. The puparia are similar to those of *pomonella*, but are only about 3.0 to to 3.6 mm in length and 1.5 to 1.6 mm in diameter.

*Host.*—The only known host in Florida is the fruit of the sparkleberry (*Batodendron arboreum*).

*Distribution.*—Apparently rather generally distributed and abundant in the northern half of Florida, the larvae being submitted for identification by almost every inspector who examined wild fruits in that part of the State. How far northward of the State line the species extends, whether it is distributed throughout the range of its host, and whether it invades other hosts in the East, such as the fruits of *Symphoricarpus*, are still open questions.

## THE GENUS ZONOSEMATA, NEW GENUS

*Adult.*—Head with vertex scarcely broader than maximum width of the narrow elongated eye, frons not tapered, flattened, produced near antennae; face with a pair of grooves to receive the antennae, the grooves separated by a flattened triangular area; tongue strong but not elongated; second antennal joint with a strong spinelike bristle, third antennal joint elongate, distally with a sharp edge and a spinelike tip; all head bristles, with the possible exception of the occipitals, strong and black; usually with four pairs of frontals, often with one or more of the individual bristles doubled, many specimens being asymmetrical in the bristling, while a single specimen has six pairs of these bristles, rarely one bristle of the normal four pairs of frontals lost; some pale hairs intermingled with a very few dark hairs on central area of frons and also forming a band near each eye; the two pairs of upper orbitals variable in size, but always long, and more or less directed outward; one pair of ocellar bristles; occipitals not long, parallel or nearly so, usually black, often one or both yellowish brown, but bristlelike and not flattened or scalelike; inner verticals variable in length, but always long,

strong, and at least slightly convergent; outer verticals long and strong; postocular cilia black, relatively strong, irregular in length; cheek bristle strong, black, well defined from the much shorter cheek cilia which are mixed luteous and black, the black cilia predominating toward the eye. Thoracic dorsum clothed with fine hairs, mostly pale, but those on the darker markings fuscous brown or black; with a pair of short, but distinct, black bristles just in back of the head and between the humeri; all of the normal thoracic bristles black; anterior supraalars well forward; dorsocentrals remote from the suture, well behind line of anterior supraalars, almost in line of postalars; acrostichals and intraalars in a line, and relatively close to caudal margin of scutum; scutellum with two pairs of long bristles. Fore and hind femora with long, black bristles. Abdomen, exclusive of the ovipositor sheath, subequal in length to the thorax, clothed with fine black hairs and terminal black bristles. Ovipositor sheath, when viewed from above, approximately equal in length to the preceding segment. Male genitalia with the forceps of the peculiar shape illustrated (fig. 15, *K*, *L*), the internal process, nearly hidden, bearing two strong teeth. Wing hyaline, with fuscous brown or blackish oblique bandings; the first and third veins spined; the anterior cross vein slightly distad of the middle of the long discal cell; anal cell produced fingerlike to a point on the sixth vein.

Type of the genus, *Trypeta electa* Say.

The new genus *Zonosemata* is *Spilographa* of Loew, 1873, in part (*60, pp. 244 and 336*); also *Spilographa*, at least in part, of Osten-Sacken, Snow, Williston, Doane, Johnson (prior to 1925), Britton, and Peterson. It is *Zonosema*, at least in part, of Coquillett, Howard, Phillips, Johnson, Johannsen, and Curran. It is also *Phorellia*, in part, of Hendel (*36, p. 28*), 1914.

Most of the species from the United States heretofore placed under the names *Zonosema* or *Spilographa* are not congeneric with *electa*, or with *vittigera* Coquillett, the latter possibly only a western race of *electa*.

Those species related to *setosa* Doane [3] will fall into *Zonosema* Loew (*59, p. 43*) of which the genotype is *Trypeta meigenii* Loew by designation of Coquillett (*14, p. 622*) in 1910. These adults have the dorsocentral bristles almost in the line of the anterior supraalars. The postalars, intraalars, and acrostichals are in line and form a transverse prescutellar row, the spines on the third vein are much reduced in number, the head is much more globular, and the male genitalia are somewhat similar to those of *Rhagoletis*. Hendel (*37, p. 74*), in 1927, considered *meigenii* congeneric with *cerasi* and accordingly placed *Zonosema* as a synonym of *Rhagoletis*. The latter genus has already been discussed in the present publication.

The remaining American species of *Zonosema* authors (=*Spilographa* authors) fall into various genera, outside of the scope of this bulletin. The generic name *Spilographa* [4] was proposed by Loew (*59, p. 39*) in 1862. Coquillett (*14, p. 607*) designated *Trypeta hamifera* Loew as the genotype. This is a European species belonging to a group feeding in the larval stages as leaf miners. The adults have the dorsocentral bristles nearly in the line of the anterior supraalars, and have globose heads, thus agreeing with the species of *Zonosema*, from which they differ on several characters, noticeably a more slender build, differently shaped antennae, and more spines on the third vein.

[3] The Doane species seems practically identical with the European *alternata* Fallen, and both feed as larvae in rose hips. Longer series will be necessary to establish the synonymy.

[4] The author omits the synonymy of the genus, for which there is at least one older name, as extraneous, only discussing the name because of prior usage to include *electa* Say, and the fact that a number of species from the western part of North America will probably fall here.

### ZONOSEMATA ELECTA (Say)

(Fig. 15, *A–O*)

Described as *Trypeta electa* by Say (*75, p. 185*) in 1830, the original description being reprinted in 1883. Osten-Sacken (*65, p. 79*), in 1858, and Loew (*57, pp. 58 and 71*), in 1862, placed the species in *Trypeta*. Loew (*60, pp. 244 and 336*), in 1873, and Osten-Sacken (*66, p. 190*), in 1878, used *Spilographa* as a subgenus of *Trypeta* to include *electa*. Thereafter several authors placed the species under the generic name *Spilographa* until 1899, when Coquillett (*13, p. 261*) introduced into American literature the name *Zonosema* for the species formerly placed in *Spilographa*. Aldrich (*2, p. 604*), in 1905, followed by several authors, dissented, and used the name *Spilographa*. Other authors adopted the name *Zonosema;* so since 1899 the specific name *electa* has been repeatedly transferred first to one and then to the other of the two generic names.

*Adult.*—Head and antennae yellowish, strongly tinged with rufous brown. Thorax with the ground color bright yellow, marked and tinted with rufous brown and brownish black, the brown forming a longitudinally banded design on the notum, as well as tinting and marking parts of the pleurae, the black spotting the areas near the bases of the wings, and the lateroproximal parts of the scutellum below the bristles. Legs yellowish. Abdomen yellowish, the terminal segment of the male and the segment preceding the ovipositor sheath of the female marked with one small black spot dorsolaterally near each proximal angle; ovipositor sheath concolorous with abdomen, except for a small amount of black at tip. Wing hyaline, with fuscous brown or blackish bandings. Size: Variable, largely depending upon the quality of the host; male usually about 6.5 mm in length, with a wing measuring about 5.6 by 2.4 mm; female usually about 7.5 mm in length, with a wing measuring about 6.5 by 2.4 mm.

Individual specimens are found which are considerably larger, but frequently the size is smaller, one specimen, a female, measuring only 4 mm in length, with a wing 4 by 1.6 mm. Some of these smallest specimens seem practically identical with a series from the Rio Grande Valley which closely match the type of *vittigera* Coq.

*Immature stages.*—Egg white, of the peculiar shape illustrated (fig. 15, *A*). Larva white, measuring, as a maximum, about 10 by 3 mm; skin conspicuously armed with minute spines tending to be arranged in irregular transverse interrupted rows near the segmental lines, and obsolescent on parts of the segments, the posterior end tuberculate, as illustrated (fig. 15, *B, D*); each anterior spiracle usually with more than 30 beads; posterior spiracles oblique, close together in a pitlike depression, spiracular plates well defined, slits on each spiracle elongate, subparallel, the sides of the individual slits more or less irregular but nearly parallel. The puparia vary much in shape, although usually tapered toward the head from a maximum width on the eighth segment; they measure from less than 6 to about 8 mm, with a diameter of 2.8 to 4.2 mm; the coloration varies between pale straw and deep rufous brown; segmental sutures plainly defined; anterior spiracles appearing as if definitely ahead of the segmental line and on the first segment; the pit containing the spiracles variable, always defined, sometimes deep, often shallow with the spiracular plates protruding, the extreme upper part of each spiracular plate usually covered by a fold or extension of the skin chitin. Both the larvae and the puparia, upon casual observation, convey an impression of belonging to some calyptrate muscoid series, yet upon study the close relationship to *Rhagoletis* becomes apparent.

*Hosts.*—The larvae of *Zonosemata electa* feed in some solanaceous fruits. Adults were reared in numbers from the fruits of *Solanum carolinense* and from *S. aculeatissimum*, the larvae normally feeding singly. Two larvae were found in a fruit of an eggplant (*S. melongena*) confiscated at a quarantine station, and a single adult was reared from these. Larvae were submitted as having been found in

tomatoes upon two occasions, and one adult fly was submitted from Georgia as having been reared from tomato (*Lycopersicon esculentum*). Peterson (*68*), in 1923, recorded the larvae, in New Jersey, as a "serious pest" of (the fruits of) various kinds of peppers (*Capsicum annuum*), and also injurious to (the fruits of) eggplants. The larvae have been recorded in *S. carolinense* by various authors. The Texas *vittigera*, mentioned in preceding paragraphs, were supplied by E. F. Pepper and J. W. Monk, the larvae feeding in the fruits of a *Solanum* stated to be *S. elaeagnifolium*.

*Distribution.*—The species is apparently abundant and generally distributed throughout the northernmost counties of Florida, and specimens were reared from fruits from various localities in St. Johns and Volusia Counties. Previously published records and the National Museum series indicate a general distribution from New York to Indiana and southward to Florida and Texas.

## THE GENUS MYOLEJA RONDANI

*Adult.*—Head with vertex narrower than maximum width of eye, frons scarcely tapered, slightly produced distally; eye narrow, third antennal joint relatively long and narrow and with apex rounded; arista slightly pubescent; all head bristles and cilia blackish; 3 pairs of frontal bristles; 2 pairs of upper orbitals; 1 pair of ocellar bristles; occipitals short and nearly parallel, slightly divergent; inner and outer verticals not conspicuously long, the latter not much longer than the postocular cilia; cheek bristle relatively strong. Thoracic dorsum clothed with fine dark hair, with the dorsocentral bristles from only slightly behind the intraalars to nearly midway between these latter and the anterior supraalars, in no case near the suture; scutellum with two pairs of long, dark bristles. Abdomen small, exclusive of ovipositor sheath, about as long as the thorax, hairy. Ovipositor sheath short and broad, when viewed from above, scarcely as long as the preceding abdominal segment. Male forceps relatively flattened and neither twisted nor incurved, the internal process with 2 moderate claws. Wing with first and third veins bristled; discal cell long and closely approaching wing margin; anal cell produced to a long point on sixth vein.

Type of the genus *Tephritis lucida* Fallén.

The generic name was first proposed by Rondani (*72, p. 112*) in 1856 for the sole species *Tephritis lucida* Fallén, which is now considered congeneric with *Musca caesio* Harris.

*Philophylla* Rondani (*73, p. 9*), proposed in 1870 for the sole species *Musca caesio* Harris, is a synonym of *Myoleja* Rondani. Hendel (*37, p. 96*) credited the Rondani name to a publication (*74, p. 175*) in 1871, but the latter represents an unallowable change of concept by Rondani.

The generic name *Euleia* was first proposed by Walker (*90, p. 81*) in 1836 for *onopordinis* Fabricius together with supposed synonyms *centaureae* Fabricius and *caesio* Harris. The Harris specific name has priority and probably represents the species actually before Walker; however, the latter point is only taxonomic supposition and has nothing to do with genotype designation. The Fabrician names have since been usually considered conspecific but are now quite generally identified as both specifically and generically distinct from *caesio*. Westwood, in 1840 (*96, p. 149*), appears to have fixed the genotype of *Euleia* as *Musca onopordinis* Fabricius (not as *onopordinis* of Walker in part, not of Fabricius). The subsequent citations of *caesio* as the genotype by Coquillett (*14, p. 541*) and other authors appear to be invalid.

According to Scudder (*78, p. 131*) the name *Euleia* has also been spelled *Euleja* and *Eulia* in the literature. Sherborn (*79*) has omitted mention of *Euleja*, which scarcely constitutes emendation, and has been unable to ascertain the place and date of publication of the emendation *Eulia*. Hendel (*37, p. 100*) stated that the name *Euleia* Walker was preoccupied, presumably because of *Eulia* Hübner, and listed the name in the synonymy of *Myiolia*. The name *Euleia* Walker is not preoccupied by *Eulia* Hübner, and, because of the Westwood type fixation, is available for the genus which Hendel (*37, p. 96*) calls *Philophylla*, and is not a synonym of *Myoleja*.

Hendel (*37, p. 100*), in 1927, emended the name *Myoleja* Rondani to *Myiolia*, which he credited to Rondani. He also spelled the Rondani name "*Myioleia*" in the bibliography.

The genotype of *Myoleja, lucida*, has the dorsocentral bristles well behind the anterior supraalars. The genotype of *Philophylla, caesio*, has the dorsocentrals almost in line with the anterior supraalars and has a somewhat different wing pattern. The sole North American species which is herein assigned to *Myoleja, limata* Coquillett, has the wing pattern and the general appearance of *caesio*, but has the dorsocentrals even farther behind the anterior supraalars than in *lucida*. In view of the general similarity of the other structures, coupled with the similarity in biology, no new generic name is proposed for *limata*.

### MYOLEJA LIMATA (Coquillett)

(Fig. 16, *A–L*)

Described as *Aciura limata* by Coquillett (*13, p. 263*) in 1899.

*Adult.*—Head luteous brown; antennae paler. Thorax luteous brown with a broad pale longitudinal band on each side of the center of the dorsum, the humeral and lateral areas pale; scutellum concolorous with the general thoracic ground color. Legs yellowish, more or less tinged with brown. Abdomen basally concolorous with the thorax, thence more or less strongly darkened, often appearing blackish. Wing hyaline much obscured by a pattern of fuscous brown which in some parts of the distal half is lightened by dull golden, the darker coloration acting as the margin of the markings. Size: Variable, depending in part upon the size and quality of the host, and in part upon the species of the host, the series of flies from any single species of holly tending to average a slightly different size from those from any other species of holly, but with complete intergradation of individuals.

Measurement of size is likely to create an erroneous impression. Among the smallest specimens are a male and a female from *Ilex cassine*, the male having a wing 3 by 1.3 mm and a length of 3.4 mm, and the female having a wing measuring 3 by 1.5 mm and a length of 3.5 mm. Among the largest specimens are some from *Ilex opaca*, one male with a wing measuring 4.5 by 2 mm and having a length of 5.4 mm, and one female with a wing measuring 4.6 by 2.1 mm and a length of 5.5 mm.

*Immature stages.*—Larva white, elongate; when fully grown, of a size proportionate with that of a corresponding adult, individuals from *Ilex cassine* measuring about 5.6 mm in length and 1.4 mm in diameter; skin appearing relatively smooth, but possessing transverse irregular rows of fine spines, noticeable on the cephalic margins of the second, third, and fourth segments; caudal segment tuberculate in the manner illustrated (fig. 16, *A* and *C*); anterior spiracles averaging 14 to 18 beads each; posterior spiracles close together but small, slits not long, but thin and nearly straight, those on each spiracle, subparallel. Puparium pale straw colored, sometimes ageing to pale brownish, of a size proportionate with that of a corresponding larva; those from *Ilex cassine* measuring about 3.5 mm in length and 1.5 mm in diameter.

*Hosts.*—The larvae feed singly in the berries of various species of holly, *Ilex,* and were found in *I. cassine, I. caroliniana, I. glabra, I. lucida, I. opaca,* and *I. vomitoria.* The puparium is formed in the ground.

*Distribution.*—The species has previously been recorded only from Massachusetts and Connecticut, but was found to be abundant and generally distributed throughout the northern half of Florida wherever the hosts were found.

## THE GENUS PROCECIDOCHARES HENDEL

*Adult.*—Head with the vertex wide, nearly twice maximum width of eye, frons tapered, flattened, somewhat distally produced near antennae; the latter with third joint short and lobate; arista somewhat pubescent; head bristles dark, except as otherwise mentioned; 3 or 4 pairs of frontal bristles, perhaps occasionally only 2 pairs, the number of pairs present not a specific character; on each side an irregular band of small pale deciduous scalelike orbital cilia, not arranged in a single row; one pair of long dark upper orbitals, not infrequently one of these doubled causing asymmetry, or both doubled creating the appearance of two pairs of bristles; with scattered, small, pale, deciduous, scalelike cilia more or less surrounding bases of upper orbitals; one pair of long ocellar bristles; inner and outer verticals strong; occipitals weak, pale, scalelike, nearly parallel, short and not well defined from the similar postocular cilia; cheek bristle inconspicuous, brown, surrounded by brownish cilia, otherwise the cheek cilia pale. Thorax, excepting the underside, the metathorax, and the scutellum, with more or less of a pattern formed by a vestiture of relatively long, pale, deciduous, scalelike pile, the exact pattern on the notum of specific significance; specifically with or without a pair of dorsocentral bristles on the prescutum in the transverse line of the presuturals; the usual dorsocentral bristles of the scutum in a line with the anterior supraalars and not close to the suture; acrostichals nearly in the transverse line of the postalars, the intraalars caudad, in consequence the acrostichals appearing relatively advanced; scutellum swollen, globose, polished, and bearing two pairs of long bristles. Abdomen, exclusive of the ovipositor sheath, approximately as long as the thorax, similarly clothed with long pile usually intermixed with darker hairs. Wing with the first vein strongly bristled; third vein naked, anterior cross vein distad of basal two thirds of the relatively elongate discal cell and close to posterior cross vein; basal cross vein margining the anal cell only slightly bent, in consequence this cell produced to a short point on sixth vein; wing pattern characteristic, the hyaline ground being marked by a dark basal spot and crossed by three dark transverse bands, the proximal two uniting to form a broad inverted V, the distal one obliquely marking the terminal area from the costa to somewhat below the fourth vein.

Type of the genus, *Trypeta atra* Loew.

The generic name of *Procecidochares* was first proposed by Hendel (*35, p. 91*) in 1914, with *atra* Loew sole species mentioned, and designated genotype. The genus was again described as new by Hendel (*36, p. 42*), and the name has since been quite generally adopted by subsequent workers, including Bezzi (*6, p. 7*) and Phillips (*69, p. 136*). Aldrich (*4*) has published a revision of the genus. The species belonging in this genus were formerly placed in *Oedaspis* Loew.

The species with known biology all cause galls on composite plants, the galls being either on the stems or in the flowering parts of the hosts.

### PROCECIDOCHARES AUSTRALIS Aldrich

(Fig. 17, *A–P*)

Described as *Procecidochares atra* variety *australis* by Aldrich (*4, pp. 2, 9*) in 1929.

*Adult.*—Head yellowish, tinged with rufous brown, and with some darker brown to fuscous brown markings; with either 3 or 4 pairs of frontal bristles, occasionally with 1 of these bristles doubled. Thorax purplish black above,

more rufous on the sides and beneath; dorsally with yellow, deciduous, scalelike hairs arising from roughened surfaces and defining 4 polished areas, one near each humeral angle, and a large one on each side of the mesonotum; scutellum globose, polished, purplish black. Legs yellowish brown, the femora and coxae tinged with fuscous brown. Abdomen blackish, with a purplish cast. Ovipositor sheath similarly colored, broad at base, narrow at tip, long, approximately two thirds length of abdomen. Male forceps strongly curved toward each other at their tips; internal processes relatively small, the usual two teeth present on each process but greatly reduced in size. Wing with oblique hyaline crossband cut in two, or nearly so, at or on third vein by an extension of the black of the terminal area, and more or less appearing as two triangular hyaline areas; the hyaline tongue, which cuts through the third posterior and the discal cells, variable in size and shape, occasionally with the edges nearly subparallel, occasionally with the edges strongly divergent and forming a triangular hyaline area; the dark markings, especially on the terminal half of the wing, more or less tinged with golden brown. Size: Male wing 2.8 by 1.2 mm, female wing 3 by 1.5 mm. Length of male 3 mm, of female 4.2 mm.

*Immature stages.*—Larva white, 3.6 mm in length and 1.65 mm in diameter, more or less dorsally marked by an irregular black blotch on the eighth, ninth, and tenth segments, sometimes indicated on the fifth, sixth, and seventh segments, stout, and of the peculiar shape illustrated (fig. 17, *A*); skin relatively smooth, skin spines obsolescent; each anterior spiracle usually with only 2 or 3 beads which are relatively large; posterior spiracles with the slits very short, broad, and rectangular, those on each of the brown, heavily chitinized, spiracular plates arranged in a fan. Puparia variable in shape, some being nearly elliptical, others decidedly shaped like an ordinary hen's egg; approximately 3.3 mm in length and 1.8 mm in diameter; segmental lines distinct.

When first formed, the puparium is practically white, and marked only by the black dorsal blotch of the larva and the brown of the posterior spiracles; subsequently the black dorsal blotch may fade to a blackish brown, and additional brown may be present as a ventral band usually extended around, and more or less obscuring, the caudal end of the puparium, in which event the white ground color is often tinged with brownish. Usually before the adult emerges the puparium has turned a deep brownish black, but adults emerged from variously marked puparia, occasionally emerging from puparia which were white save for the darker larval markings.

*Hosts.*—Adults were reared from larvae and puparia found in galls on *Heterotheca subaxillaris* and *Erigeron pusillus*, commonly on the former and much more rarely on the latter. The galls were usually found on young shoots of plants that had not bloomed, occasionally in older more woody stems, and sometimes in the flowers. Some of the galls are of a size allowing only sufficient room for a single puparium; others were larger, containing from 2 to 8 larvae or puparia. All of the galls were difficult to see, being more or less hidden by clusters of young leaves which formed a part of the gall and by the dense natural clustering of the leaves of the host plant, or being hidden among the flowers, or rarely in a flower. As many as 6 or 7 galls were found on a single plant.

*Distribution.*—The species was formerly known only from the type female "reared at Waco, Texas, by W. Dwight Pierce, from the head of *Heterotheca subaxillaris*" and two males which formed a part of the type series, one from Llano, Tex., the other from Orlando, Fla. A single adult specimen was captured by an inspector at Brooksville, Fla., and subsequently galls were found in quantity at Orlando and several other localities in Orange County. The species is probably more generally distributed than indicated by the foregoing records, as the galls can scarcely be found except by feeling the stems of the host for swellings.

## THE GENUS PERONYMA LOEW

*Adult.*—Head with vertex more than twice as broad as maximum width of the narrow eye; frons scarcely tapered, more or less produced near antennae; second antennal joint with a conspicuously long bristle as well as the shorter bristles; third antennal joint almost lobate; head bristles short, but heavy and black excepting as otherwise noted; 2 pairs of frontal bristles; a band of pale, deciduous, scalelike hairs on each side of front near each eye, with similar but scattered hairs near center of frons; a patch of very small black bristles in center of frons near antennae; 1 pair of upper orbital bristles, the bristle on either side occasionally doubled; 1 pair of ocellars; inner verticals somewhat convergent, not much longer than the sharply divergent outer verticals; occipitals weak, deciduous, short, variable from nearly parallel to strongly divergent, usually pale, abnormally somewhat darkened at tips; postocular cilia pale, deciduous, scalelike; cheek cilia pale, long, the cheek bristle not longer than the cilia, either black or pale; a black patch on second antennal joint; tip of third joint blackened; a black patch on each side of mouth; another on each of the cheeks, contiguous with each eye; another between each of the eyes and the antennae; a conspicuous rounded black mark at base of each of the black facial bristles; tongue short, but the palpi conspicuously enlarged and lobate. Thoracic dorsum with a mixed vestiture of short, pale, scalelike hairs and black stubble; all of the ordinary bristles short but heavy and black, the dorsocentrals in a line with the anterior supraalars but remote from the suture; scutellum much swollen, but more or less divided into 2 lobes, and bearing 2 pairs of bristles, the apical pair usually much weaker than the proximal pair (according to prior descriptions possibly some specimens possess only the proximal pair of bristles), each bristle of thorax and scutellum arising from a conspicuous rounded black spot; a pair of large, black spots on the suture. Abdomen, exclusive of the ovipositor sheath, broad, about as long as the thorax; proximal segment apically banded, with short, black stubble; the four following segments clothed with sparse, short, black stubble. Ovipositor sheath nearly as long as the preceding abdominal segments, rounded above, somewhat flattened below, on each side marked by a strong lateral ridge. Male genitalia with the forceps twisted and ridged; the internal process heavily chitinized at the tip and bearing two short claws. Wing with oblique dark bands; costa distorted; first and third veins spined; anterior cross vein oblique and close to the slightly S-shaped posterior cross vein; discal cell long, narrow basally, broad distally; anal cell produced to a short point on the sixth vein.

Type of the genus, *Trypeta sarcinata* Loew.

The generic name *Peronyma* was proposed in 1873 by Loew (*60, pp. 247, 250*), who gave it generic rank, yet treated it as of subgeneric significance under the generic name *Trypeta*. Osten-Sacken (*66, p. 190*), in 1878, used the name as subgeneric under *Trypeta*. Subsequent authors, including Aldrich (*2, p. 605*), Coquillett (*14, p. 587*), Hendel (*35, p. 87* and *36, p. 6*), Phillips (*69, p. 130*), and Curran (*22, p. 2*) have adopted the name as generic. The generic name *Tomoplagina*, which the writer considers a synonym, was proposed by Curran (*22, pp. 4, 14*) in 1932 for the new species *maculata*, solely included species and designated genotype.

All stages, from egg to adult, indicate a close relationship to *Eurosta*, which is further substantiated by the biology.

### PERONYMA MACULATA (Curran)

(Fig. 18, *A–R*)

Curran (*22, pp. 4, 14*) described *maculata* as a new species in the new genus *Tomoplagina*. Loew (*58, p. 218, no. 73*), in 1862, described a species from "Carolina" as *Trypeta sarcinata*. The subsequent references to *sarcinata* are the same as those listed under the present generic heading. Macquart (*61, p. 383*), in 1843, described a species from Georgia as *Tephritis quadrifasciata*, but the Macquart name is a secondary homonym of "*Trypeta quadrifasciata*" Meigen. The

writer believes that only a single species is involved, but until the synonymy can be definitely established by further rearings, he prefers to use the name *maculata* Curran for the Florida series with the warning that the name will probably prove to be a synonym. The apical bristles are easily lost from the scutellum, the thorax and scutellum frequently darken with grease, the exact extent of the markings on the wing is variable, and the oblique hyaline band distad of the anterior cross vein is nearly joined with a hyaline costal spot in occasional specimens from Florida, but none are quite like the Loew figure (*60, pl. 11, fig. 16*). One specimen in the Museum of Comparative Zoology agrees fairly well with the Loew description and figure, but is so stained that the original ground color is not evident. The single specimen from Alabama, discussed and figured by Phillips, is stated to have a "shining black" scutellum, but appears to have the wing pattern of the Florida series. The Macquart type of *quadrifasciata* is stated to have a brown thorax, but the wing pattern is like that of the Loew figure. The only specimen in the National Museum collection is labeled as coming from southern Georgia (Morrison) and, while very old and in very bad condition, agrees perfectly with the Florida series, specimens of which were matched with the Curran type.

*Adult.*—Head, including antennae, luteous, conspicuously marked with black. Thorax luteous, pollinose, and marked by conspicuous black spots, with a paired. broad, more or less obsolescent, brown stripe on each side of center of dorsum; scutellum luteous, marked with black spots at bases of bristles, with 2 dorsoproximal black patches tending to suffusion, and with 2 similar patches on the underside; metathorax marked with fuscous brown patches. Legs more or less concolorous with the head and thorax, unmarked by dark patches or spottings. Abdomen, exclusive of the luteous brown, black tipped ovipositor sheath, luteous, more or less tinted with brown. Wing with a pattern of oblique golden brown bands which arise from a similar costal coloration, the golden brown margined by fuscous. Size: Wing of male 4.5 to 5 mm by 1.8 to 2 mm, of female 5 to 6 mm by 2 to 2.4 mm. Length of male 4.2 to 5 mm; female actually measuring about 5.5 to 5.6 mm but in reality much longer, the abdomen and the ovipositor sheath each strongly convex dorsally, so the ovipositor sheath, while more or less in a cephalocaudal line, is almost at a right angle to the dorsum of the last ordinary abdominal segments.

All specimens which are not freshly emerged or which have not been freed from grease tend to have the brownish and luteous colorations darkened, and appear brown or rufous brown. For further details of the black markings, which are of superficial generic significance, consult the generic description and the figures.

*Immature stages.*—Egg white. Larva white, soft, stout, the largest larva found measuring 5 mm in length by 3.4 mm in diameter; segments conspicuous; skin finely and densely stippled with minute spines although appearing relatively smooth; anterior spiracles with about five to seven beads; posterior spiracles small, widely separated; spiracular plates on the surface inconspicuous, those below the surface strong, and brown; slits short, often irregular in outline, but sometimes almost ovate, and sometimes nearly parallel sided, those on each spiracle arranged in a fan. Puparium pale brown, more or less tinted with darker to fuscous brown, especially on ends; measuring from 4.5 to 5.4 mm in length and from 2.4 to 2.9 mm in diameter, the diameter apparently less than that of a corresponding larva; sutural lines not distinctly visible.

*Host.*—The larvae feed in *Chrysopsis trichophylla*, in irregularly shaped galls, usually on the stems, but sometimes at the bases of the flowers, or on the tender growth from the root crowns. The galls are usually compound, and may contain from 1 to 8 separate cells with a single larva or puparium in each. The larva before forming

a puparium makes an exit place in the gall, only a thin and easily ruptured covering sealing the emergence hole.

*Distribution.*—Exclusive of the Carolina, Georgia, and Alabama specimens mentioned in the discussion, and which may not be conspecific, the species is known to the author only from the single type of *maculata* from Gotha, Fla., in the American Museum of Natural History, from the single specimen labeled as having been collected in southern Georgia by Morrison, and from the reared Florida series from 1 locality in Lake County and 4 localities in Orange County. The species seems restricted to local colonies each of which contains numerous individuals. All of the colonies which were found were on plants growing in a moist environment.

## THE GENUS EUROSTA LOEW

*Adult.*—Head with vertex approximately twice as broad as maximum width of constricted eye, frons scarcely tapered, produced near antennae; third antennal joint broad and more or less lobate; arista pubescent; head bristles relatively short, black, except as otherwise stated; usually with three pairs of frontal bristles, the upper two pairs often close to margins of eyes, and resembling lower orbital bristles, the lower pair remote from eyes, sometimes pale and scalelike; two pairs of upper orbitals, the upper pair pale and scalelike or dark and subequal to lower pair, variable within individual species, frequently either bristle of the upper pair doubled, occasionally one of the bristles of the lower pair doubled; one pair of ocellar bristles; inner verticals usually strongly convergent; outer verticals usually strongly divergent; occipitals pale, weak, deciduous, scalelike, usually somewhat divergent; postocular cilia pale, deciduous, scalelike, mixed with short dark bristles; cheek bristle usually not defined from the strong cheek cilia. Thoracic dorsum clothed with small, pale, scalelike hairs; dorsocentral and anterior supraalar bristles well behind suture but nearly in a line, variable individually within single species, but usually with dorsocentrals somewhat in front of line of anterior supraalars in *solidaginis* and in *nicholsoni* and usually slightly behind line of anterior supraalars in *comma* and in *reticulata*, the anterior supraalar bristles frequently doubled on one or on both sides of the dorsum of individual specimens, the dorsocentrals occasionally similarly doubled, specimens of *solidaginis* sometimes with the paired dorsocentrals replaced by tufts containing several bristles; scutellum swollen, markedly convex, usually with 1 or 2 pairs of long bristles, but varying individually by possessing from 2 to 7 bristles within a single species. The doubling of almost any of the bristles is a trait possessed in common by the various species in the genus. Abdomen broad, usually somewhat longer than thorax, dorsally clothed with short, dark, glistening hairs, intermixed with some pale scalelike hairs, especially on the basal segment. Ovipositor sheath short, but not conspicuously broad. Ring of second male genital segment broad and conspicuously differentiated from the much narrower forceps; internal process with two strong teeth. Wing with a dark pattern obscuring most of the ground, but broken by hyaline and semihyaline incisions and droplets; first and third veins bristled; a single known species, *latifrons* Loew, with a well-defined callus in the first posterior cell, the other species with the callus variable, less well defined, but always causing a bending of the third vein; anterior cross vein approximately at distal third of discal cell; anal cell more or less bluntly pointed on sixth vein.

Type of the genus, *Acinia solidaginis* Fitch.

All of the species with known biology form galls on the roots or stems of goldenrod (*Solidago* spp.). Each larva before forming a puparium makes an exit in the gall, only a thin and easily ruptured covering sealing the emergence hole. The different species of *Eurosta*, at least locally, tend to be restricted to different species of *Solidago;* although, if the previous literature is accurate, different goldenrods may serve as hosts for a single species of *Eurosta* in different localities. Plants growing in a moist environment seem more subject to attack than those in dryer soils.

The generic name was proposed by Loew (*60, p. 280*) in 1873 for *solidaginis* Fitch, but *comma* Wiedemann and *latifrons* Loew were also included. Coquillett (*14, p. 543*), in 1910, definitely designated *solidaginis* as the genotype. Osten-Sacken (*66, p. 192*), in 1878, listed *Eurosta* as a subgenus of *Trypeta* and (*66, p. 260*) stated that the name *Eurostus* Dallas does not conflict, but "should a change be thought necessary, add the syllable *Neo.*"

Curran (*22, p. 4*), in 1932, proposed the monobasic generic name *Eurostina* with *Trypeta latifrons* Loew designated genotype, giving as the separating character from *Eurosta*, "anterior pair of dorsocentral bristles situated close to the suture." This is not the case in the single specimen of *latifrons* in the collection of the United States National Museum. In this specimen there is but a single pair of dorsocentrals, and these are remote from the suture and only slightly in front of the line of the anterior supraalars; hence the Curran name is placed as a synonym.

### EUROSTA NICHOLSONI, new species

(Fig. 19, *A–M*)

Closely related to *Eurosta solidaginis* Fitch,[5] and making similar, but much smaller, galls on the stems of a species of goldenrod. It differs from that species in that the adult has a greater extension of dark markings, and consequently less hyaline, on the wing. The male genitalia show slight differences which may or may not be significant when sufficient material from various colonies of both species is examined. The larvae average 1 or 2 fewer beads on the anterior spiracle than those of the available limited series of *solidaginis*. The posterior spiracles are similar. The larvae of both seem too variable to be distinguished by other characters.

*Adult.*—Head, including the antennae, yellowish, more or less tinged with rufous. Thorax with a rufous ground covered with bright pollinose yellow which speedily becomes obscured by grease, with some obscure dark markings tending to be arranged in longitudinal bands on the dorsum; scutellum similar in coloration to the thoracic dorsum, with from 2 to 4 bristles, the posterior pair usually present but normally much weaker than the proximal pair. Legs yellowish, more or less tinted with rufous. Wing with the pattern mostly blackish brown and luteous brown, interrupted by some hyaline spots. Size: Wing usually measuring about 7.5 by 3.25 to 3.5 mm, the wings showing little difference in size between the sexes. The male approximately 7 to 7.5 mm in length, the female 0.5 to 0.75 mm longer.

*Immature stages.*—Similar to the corresponding stages of *E. comma*; the larva and the puparium possibly averaging 0.25 to 0.5 mm longer. Anterior spiracles usually with from 3 to 5 beads each; posterior spiracles closer together, and the slits on each spiracle arranged in an oblique line with their apices pointed more in a lateral than in a ventral direction.

*Hosts.*—The larvae feed in small round galls on the stems of goldenrod (*Solidago* sp.).

*Distribution.*—This species was found only near the east coast, in Brevard County, Fla., but in several localities. Adults were reared from galls which came from near Titusville, from near Malabar, and from 5½ miles southwest of Indian River. The holotype male and

[5] Described by Harris (*34, p. 417*) in 1841 as *Tephritis asteris*, but this name is a primary homonym of *T. asteris* Haliday (*32, p. 186*) described in 1838; hence unavailable. The species was again described as new by Fitch (*28, p. 771*) in 1855, and given the name *Acinia solidaginis*. The Say manuscript name *nuphera* was mentioned by Harris (*33, p. 80*) in 1835, and by Osten-Sacken (*65, p. 77*) in 1858. This name was made available by Johnson (*54, p. 97*) in 1925. The only known "type" of both the Harris and Johnson (Say manuscript) names is discussed by Johnson. The author has personally compared this "type" with a specimen which agrees perfectly with the Fitch types of *solidaginis* in the United States National Museum.

allotype female are from 1¼ miles south of Titusville, the remaining series of 8 males and 6 females (paratypes) from 1½ miles south of Titusville, from near Titusville, and from 1 mile south of Malabar, all from Brevard County, Fla.

### EUROSTA COMMA (Wiedemann)

(Fig. 20, *A–M*)

Described as *Trypeta comma* by Wiedemann (*97, p. 478*) in 1830, and since discussed by many authors. It was figured by Loew (*57, pp. 58, 93*) (*60, pp. 280, 336*), Daecke (*23. p. 342*), Phillips (*69, p. 144*), and others.

*Adult.*—Head, including antennae, yellowish, more or less tinged with rufous. Thorax with a rufous ground, and covered with a bright pollinose yellow which speedily becomes obscured with grease; some obscure darker markings, tending to be arranged in longitudinal bands on the dorsum; dorsocentral bristles as well as other thoracic bristles occasionally doubled; scutellum similar in coloration to the thoracic dorsum; with from 2 to 7 bristles, reduced in numbers owing to the obsolescence of the posterior pair, or increased in numbers owing to some of the ordinary bristles being doubled. Legs concolorous with thorax. Wing with pattern blackish brown, luteous, and hyaline. Size: Aside from dwarf individuals, the wings of both sexes with little variation in size, usually measuring 7.25 to 7.75 mm by 3 to 3.25 mm. Male about 7 to 7.5 mm in length, female approximately 1 mm longer than a corresponding male.

*Immature stages.*—Egg white. Larva white, soft, when fully matured measuring from about 6 to 7 mm in length and sometimes more than 4 mm in diameter; skin densely clothed with minute spines; anterior spiracles usually with about 6 or 8 beads each; posterior spiracles widely separated; spiracular plates on surface inconspicuous and poorly chitinized, those below the surface strong, brown, irregular in outline; slits short, broad, ovate, and arranged in a fan on each spiracle. Puparium similar to the larva, but straw colored and slightly smaller.

*Hosts.*—The larvae normally feed in galls on the roots of goldenrod (*Solidago*), growing in damp or wet soils. Occasionally the root galls project above the surface of the ground. Sometimes galls are formed on the stems, especially when the roots of the host are covered with water, during oviposition. A patch of infested goldenrod will frequently yield many galls, often several on the roots of a single plant, but with only a single larva or puparium in each gall. The infestations are usually in the form of local colonies. There are many species of closely related goldenrods in Florida, and possibly more than a single species serves as host. One species was identified, through the courtesy of authorities at the United States National Museum, as *Solidago fistulosa.* Daecke (*23, p. 342*) recorded the host on Long Island, N.Y., as *S. juncea.*

*Distribution.*—The species is locally and colonially abundant in the northern half of Florida, and has previously been recorded from localities ranging from Maine to Virginia and Kentucky. Records from the West and Southwest possibly refer to *Eurosta fenestrata* Snow, which, in turn, may ultimately be proven only a western variant of *comma.* Johnson recorded *fenestrata* from St. Augustine, Fla. (*52, p. 84*).

### EUROSTA RETICULATA Snow

(Fig. 21, *A–M*)

Described as *Eurosta reticulata* by Snow (*83, p. 170*) in 1894. The author is unable to differentiate *Eurosta conspurcata* Doane (*25, p. 186*), described in 1899, from this species. The Florida series has the wing pattern variable, but on the whole with some of the hyaline

markings in the third posterior cell so coalescing that an irregular hyaline area is formed, thus more closely resembling Doane's figure of *conspurcata* than Snow's figure of *reticulata*. The biology has been discussed by Thompson (*87, p. 71*) and Stebbins (*85, p. 52*).

*Adult.*—Head, including antennae, yellowish, more or less tinged with rufous. Thorax, including scutellum, with a rufous ground tinted with luteous and marked by black which forms a broad band each side of center of dorsum, a blotch mesad of humerus, a broad band on each side of mesothorax between dorsocentral and intraalar bristles, a similar band touching base of anterior supraalar and extending between intraalar and postalar bristles, a spot at base of acrostichal bristles, and obscure dark marks on scutellum; entire thorax densely pollinose, this more or less completely hiding the ground color and black markings, causing the thorax to appear either silvery gray, or, when slightly greasy, ranging from luteous gray to almost golden, or, when soaked by grease, or when wet, allowing the ground color and markings to become visible; dorsum clothed with small, pale, scalelike hairs, except that those which arise from the dorsolateral area of the mesothorax are usually dark, but any of the pale hairs which have been soaked by grease may appear quite dark; scutellum usually four bristled. Legs yellow, more or less tinted with rufous. Wing with the pattern fuscous brown, luteous brown, and hyaline, presenting a banded, yet reticulated, appearance. Size: The wings show little difference in size as between the sexes, and usually measure slightly less than 7 mm in length and from 2.75 to 3.1 mm in width. Male usually from 5.5 to more than 6 mm in length, and the female about 0.5 mm longer.

*Immature stages.*—Similar to corresponding stages of *E. comma*, the larva and puparium possibly averaging somewhat shorter. The anterior spiracles usually have from 6 to 8 beads. The posterior spiracles are almost identical with those of *comma*, but are usually somewhat closer together.

*Host.*—The larvae feed in root galls on goldenrod (*Solidago sempervirens*). From 1 to 4 galls were found on a single host plant. Those having galls were growing in soil subject to standing brackish water during spring and summer. These galls, which may attain a length of over 45 mm and a diameter greater than 25 mm, are normally just below the surface of the ground. Usually each gall contains only a single larva or puparium, but very occasionally the galls are compound, containing two larvae or puparia separated by a thin partition.

*Distribution.*—The species was found in some numbers, but only by D. J. Nicholson and in a single locality 4 miles west of Indian River City, Brevard County, Fla. Previously published records, and the National Museum series, indicate a distribution from Maine through the Northeastern States westward to at least Montana and Colorado. The species appears to be restricted to certain localities and in those it is found in isolated colonies.

## THE GENUS PARACANTHA COQUILLETT

*Adult.*—Head large; vertex somewhat wider than maximum width of relatively narrow eye; frons scarcely tapered in width, produced; third antennal joint slightly curved; arista with cilia short; head bristles strong and black, or yellow and scalelike; 3 pairs of erect, scarcely converging frontal bristles, the lower pair yellow, the upper 2 pairs black, close to the eyes and resembling lower oribtals; 3 pairs of pale, erect bristles inside of frontals between middle of front and vertex, possibly being the upper orbital bristles which are otherwise absent; inner verticals black; outer verticals yellow inconspicuously differentiated from the yellow postocular cilia; a strong pair of black ocellar bristles; occipitals yellow, divergent; postocular cilia mixed, yellow and shorter black bristles; cheek cilia mostly yellow, intermixed with some dark hairs; cheek bristle relatively strong, blackish. Thoracic dorsum with a reticulate pattern of yellow pile; dorsocentral bristles in front of anterior supraalars and close to suture; scutellum with two pairs of strong black bristles and a distal fringe of scalelike hairs, dorsally bearing some additional paired, long, scalelike hairs. Abdomen broad, tapered, short; exclusive of ovipositor of female, subequal in length with

thorax; dorsally clothed with pale scalelike hairs, and with dark short hairs along cephalic margin of segments. Ovipositor sheath broad, comparable in length with that of the 3 or 4 preceding abdominal segments; male forceps relatively short and twisted, the distal edge of the second genital segment sharp and either serrate or knifelike, the internal process with two strong claws, the anal region not large. Wing with the first vein bristled; stalk of second and third veins with 1 or 2 bristles; third vein naked; anterior cross vein at approximately the beginning of the distal third of the discal cell; anal cell broad, but drawn out as a long projection on sixth vein. In addition, the conspicuous black spots between and surrounding the antennae, and the peculiar maculation of the wings, will aid in the isolation of the genus.

Type of the genus, *Trypeta culta* Wiedemann.

The generic name *Paracantha* was first proposed by Coquillett (*13 p. 264*) in 1899 with *culta* sole species and designated type. This is the *Carphotricha* of some of the earlier authors and of Loew in part, a name generally used to include the species belonging in *Paracantha* until as late as 1910 when Coquillett (*14*) published his paper on the genotypes of American Diptera.

The genus contains several closely related species which have been generally confused in the literature.

### PARACANTHA CULTA (Wiedemann)

(Fig. 22, *A–P*)

Described as *Trypeta cutta* by Wiedemann in 1830 (*97, p. 486*) but this spelling obviously a typographical error corrected in the index of the original publication (*97, p. 680*) to *culta*. The latter spelling has been consistently employed by a long list of authors excepting Osten-Sacken (*65, p. 79*) in 1858. Macquart (*61, p. 385, pl. 31, fig. 5*), in 1843, redescribed the species under the new specific name *fimbriata*. The species seems to have been much confused in the past with *cultaris* Coquillett (*12, p. 72*) and with neotropical species. Records of *culta* from the Pacific coast from Mexico and from Central America and South America are not to be trusted.

*Adult.*—Head yellow, tinged with some brown, with conspicuous black patches as illustrated, also with an additional black patch behind each eye. Dorsum of thorax with a brownish ground color, interrupted by four irregular yellowish longitudinal stripes bearing yellow pile, creating the appearance of a yellowish thorax marked by brownish dots; humeral areas yellow; with a yellow lateral line; otherwise more or less tinged with brown somewhat interrupted by yellowish; scutellum yellowish brown, conspicuously marked by a black spot at base of each of the posterior, black, scutellar bristles. Legs yellowish brown, the fore femora each with a black spot, the mid and hind femora each with two black spots. Abdomen yellowish, more or less tinged with brown. Wing brownish orange on the disc, the coloration extending in rays bordered by fuscous to wing margin; the orange coloration often obscured or replaced by fuscous in the distal parts of these rays; spaces between the rays hyaline; ground color further mottled by hyaline spots with fuscous margins and shadings, and a conspicuous jet-black callus in first posterior cell; two rays between apices of third and fourth veins, the upper ray usually reduced to a terminal fuscous streak and not connected with the ground color of the wing, the lower ray oblique, nearly touching apex of fourth vein. Male forceps twisted, distal edge of second genital segment sharp and serrate. Ovipositor sheath approximately as long as total length of the four preceding segments. Size: Male wing 6 by 2.8 mm, female wing 7.4 by 3.5 mm. Length of male 6.5 mm, of female 8 mm.

*Immature stages.*—Egg white, with a long tapering stalk. Larvae white, with variation in size, when fully grown from about 6.1 to 7.6 mm in length and from about 2.8 to 3.4 mm in diameter; skin with an evenly scattered stippling of fine spines and appearing granular in consequence; each anterior spiracle with about nine beads; posterior spiracles with the slits parallel sided and relatively straight, each spiracle with the slits arranged in a fan with the lowest slit relatively more

oblique than the upper two. Puparia dark brown to blackish, each of a size comparable with the fully grown larva from which it was formed, about 0.5 mm shorter and 0.25 mm larger in diameter; segmental lines poorly defined but visible.

*Host.*—The larvae feed in the bases of the flowers of thistles, *Cirsium* sp., from 1 to 12 having been found within a single flower. Occasionally, especially before the blossoming period, larvae were found within the tender growing stems. Adults were obtained from *C. nuttallii*, from *C. horridulum* (*C. spinosissimum*), and probably from other species of thistles.

*Note.*—About 400 reared specimens of *culta* showed no intergrades with the following species.

#### PARACANTHA FORFICULA, new species

(Fig. 23, *A–M*)

Resembling *Paracantha culta* Wiedemann in all details of egg, larva, puparium, and adult, except as follows:

*Adult.*—Averaging about 25 percent smaller than *culta;* the facial black markings reduced in size, the spot on each side of the face and contiguous with the eye reduced to a heavy black dot and not elongate; with powdery black surrounding bases of all scutellar bristles, the black marking the bases of the apical pair of greater extent than in *culta* but less conspicuous because of its powdery nature; wing with hyaline droplets in axillary and third posterior cells tending to be more strongly defined by fuscous, the ray near center of distal hyaline area of first posterior cell usually connected with ground color of basal portion of cell, and the following ray nearly equally dividing remainder of hyaline area. Second genital segment of male with the distal portion drawn out to a knifelike edge but lacking definite teeth or serrations. Ovipositor sheath relatively short, being subequal to the last three preceding segments. The chitinous ovipositor only about 1.1 mm in length, as compared with 2.3 mm for that of *culta*, but similar in width, both being 0.4 mm.

*Immature stages.*—The egg, illustrated in figure 23, *A*, was removed from a female, while that of *culta* was laid by the female; hence no true comparison can be made between these eggs. The fully matured larva averages 25 percent smaller than that of *culta*, being somewhat smaller than the smallest fully matured larva of the latter. There are on an average 1 or 2 less beads on each anterior spiracle, and the slits of the posterior spiracles are shorter while remaining nearly as broad. The puparium is similar to that of *culta*, but about 25 percent smaller.

*Host.*—The larvae feed in the soft fleshy bases of the flowers of *Borrichia frutescens*, usually 1 to a flower but occasionally 2 or 3 in 1 flower.

The types are 100 adult specimens about equally divided as to sex, all reared by D. J. Nicholson from larvae or puparia from the following Florida localities: Cocoa Beach, Merritt Island, Key Largo, Jasmine Point, Naples, Boca Ciega, and Miami Beach. Dates of emergence range from May 2 to June 30, 1930, with the exception of a single emergence on October 21, 1930. The holotype male and allotype female are designated from Cocoa Beach, and the remaining 98 specimens are paratypes.

### THE GENUS ACIDOGONA LOEW

*Adult.*—Head relatively broad, vertex slightly wider than maximum width of eye, frons tapered in width and distally produced; third antennal joint pointed; arista somewhat pubescent; head bristles black except the postocular cilia, the cheek bristles and cilia, and, occasionally, the occipitals; 3 pairs of frontal bristles, the upper 2 pairs close to the margins of the eyes and resembling lower orbital bristles; 2 pairs of upper orbitals; 1 pair of ocellar; each inner vertical close to the corresponding outer vertical; occipitals short, slender, dark or pale, nearly

parallel; the occiput also bearing an inner pair of deciduous, weak, convergent, scalelike hairs; cheek bristle relatively dark and strong. Thoracic dorsum clothed with yellow pile, with the dorsocentral bristles approximately in line with the anterior supraalars close to the suture; scutellum with 2 pairs of strong black bristles, and an apical and 2 subapical pairs of pale deciduous, scalelike hairs. Abdomen short and broad, covered with yellow pile intermixed with black bristly pile. Ovipositor sheath short, slightly longer than the preceding segment. Male forceps conspicuously narrower than the dorsal part of the second genital segment, the internal process with two strong claws, the anal region relatively small. Wing with the first vein strongly bristled; the course of the second vein interrupted by an excurve above the posterior cross vein; the stalk of the second and third veins bristled; with about 4 bristles on third vein distad of stalk of second vein and 1 more bristle distad of the anterior cross vein, which is somewhat distad of middle of discal cell; anal cell relatively short and broad, produced on the sixth vein to a short but acute point.

Type of the genus, *Trypeta* (*Acidogona*) *melanura* Loew.

*Acidogona* was first proposed by Loew (*60, p. 285;* but on *p. 300* spelled *Acidigona*), as a subgenus of *Trypeta*, for *melanura* as sole species.

#### ACIDOGONA MELANURA (Loew)

(Fig. 24, *A–N*)

Described as *Trypeta* (*Acidogona*) *melanura* by Loew (*60, p. 283, pl. xi, fig. 6*) in 1873.

*Adult.*—Adult characters, excepting coloration, as under the generic heading. Head including antennae pale luteous brown, ventrally and caudally paler; thorax with the dorsum blackish, the humeral and lateral areas luteous, the lateroventral and ventral areas blackish brown; scutellum brownish luteous, conspicuously marked with black and blackish brown, which forms disconcolorous spots at bases of bristles and darkens a large cephalomedian area. Legs bright yellow. Abdomen bright luteous, with conspicuous median and lateral black spots as illustrated; beneath luteous. Wing brown and blackish brown with hyaline spots, measuring 3.75 by 1.75 mm as an average for normal individuals.

*Immature stages.*—Egg white. Larva white, shaped as illustrated in figure 24, *B*; each anterior spiracle averaging six beads; posterior spiracles widely separated, the slits ovate, their position (fig. 24, *D*) abnormal for the family. Puparium dark brown, the segmental sutures obsolescent.

*Hosts.*—The larva feeds singly in an individual flower of *Hieracium*, the egg being deposited in the young bloom, which remains tightly sealed until the adult emerges. Adults were obtained from flowers of *H. argyraeum*, *H. scabrum*, and *H. gronovii*.

*Distribution.*—The species has heretofore been very rare in collections, and the only records seem to be that of the type from Washington, D.C., and the Massachusetts record of Johnson (*53, p. 264*).

### THE GENUS TOMOPLAGIA COQUILLETT

*Adult.*—Head with vertex wider than maximum width of eye, frons tapered, flattened, somewhat produced near antennae; antennae with third joint lobate; arista without noticeable pubescence; head bristles all pale but definitely of a bristly nature with the exception of the occipitals; three pairs of frontals, and some scattered thin pale hairs near margin of each eye; two pairs of upper orbitals; one pair of long ocellar bristles; about six pairs of short hairs on ocellar triangle, and one pair of similar hairs on occiput just behind ocellar triangle; inner and outer verticals strong; occipitals nearly parallel, somewhat flattened and scalelike, conspicuously longer than the postocular cilia, which are small and pale but definitely hairlike; cheek bristles and cilia relatively strong. Thoracic dorsum clothed with short, sparse, bristly hairs; all of the normal bristles yellowish but strong; dorsocentrals much in front of the line of the anterior supraalars and close to the suture; acrostichals relatively far forward but behind the line of the anterior supraalars; scutellum bearing two pairs of strong but yellowish bristles. Abdomen clothed with sparse bristly hairs which appear either fuscous or luteous depending on the lighting. Ovipositor sheath broad, and relatively long in comparison with

the length of the abdomen. Wing with the first vein, the knot at the junction of the second and third veins, and the third vein, bristly; anterior cross vein strongly oblique; fourth vein excurved near base of second posterior cell; discal cell long and approaching the margin; anal cell produced to a long point on the sixth vein. The diagonally banded wings, coupled with the presence of at least some black spottings on the thorax and on the abdomen, are superficial characters suggestive of the genus.

Type of the genus, *Trypeta obliqua* Say.

The generic name was proposed by Coquillett (*14, pp. 591, 615*) in 1910 to replace *Plagiotoma* Loew, preoccupied, with *obliqua* designated type. The generic name *Plagiotoma* had been proposed by Loew (*60, p. 252*) in 1873 as a subgenus of *Trypeta*, with *obliqua* designated the type (*60, p. 337*). The Loew name is preoccupied by *Plagiotoma* Claparède and Lachmann, 1858, a name for a genus of Protozoa.

### TOMOPLAGIA OBLIQUA (Say)

(Fig. 25, *A–L*)

Described as *Trypeta obliqua* by Say (*75, p. 186*) in 1830, placed in *Trypeta*, subgenus *Plagiotoma*, by Loew (*60, pp. 251, 337*) in 1873, and thereafter usually cited as *Plagiotoma obliqua* until Coquillett proposed the anagram *Tomoplagia* in 1910. Since that date the combination *Tomoplagia obliqua* has been in general use. The important references are mostly cited by Hendel (*36, p. 35*), excepting the subsequent paper by Phillips (*69, p. 133*) and the record from Lower California by Cole (*11, p. 472*).

*Adult.*—Head, thorax, abdomen, and legs yellow, more or less tinged with lemon yellow, the scutellum bright lemon yellow. Thorax marked by black spots; one on each side of the mesonotum near the scutellum, one above the mid coxa, one above the hind coxa, and one near base of abdomen on each side; and a black dot just behind the base of each wing. Abdomen marked on each side by a dorsolateral row of black spots resembling buttons, the individual spots in each row about equally separated, one spot on each side of each visible segment, excepting the ovipositor sheath; thus the male has a total of 8 abdominal spots, and the female, 10. Ovipositor sheath broad, but approximately of a length equal to that of the three preceding segments. Male forceps twisted and also bent inward toward each other; each internal process with one relatively long claw and one short spinelike claw. Size: Male wing, 3.9 by 1.6 mm; female wing, 4 by 1.65 mm. Length of male 3.3 mm, of female 3.9 mm.

*Immature stages.*—Larva white, relatively stout, approximately 2.85 mm in length and 1.1 mm in diameter, marked by black which obscures much of the last segment and forms a dorsal mark on the preceding segment; skin coarsely granular; last segment with small but conspicuous tubercles; each anterior spiracle with 4 or 5 beads (the only larva examined which possessed 5 beads had 3 of these beads closely crowded, the larvae which possessed 4 beads had these beads symmetrically arranged); posterior spiracles with the slits small but elongate, those on each spiracle arranged in a fan. Puparium about 2.4 mm in length by 1.2 mm in diameter; the segmental lines variable but indistinct; dull brownish in color but marked with black similar to that of the larva.

*Hosts.*—Adults were reared from larvae and puparia in flowers of *Vernonia scaberrima*, *V. blodgetti*, and *V. gigantea*. Only an occasional flower is infested; and it contains a single larva or puparium, which is difficult to find.

*Distribution.*—Apparently rather generally distributed throughout Florida, including the Keys, and not rare, although never found in abundance. The species was originally described from Indiana. Other records cite New Jersey, Pennsylvania, Illinois, Iowa, Kansas, California, and New Mexico; also Mexico (Guadalajara, Orizaba, Vera Cruz, and San Pedro Martir Island, Lower California), and

Cuba. Owing to the large number of very closely related tropical species, records from the West Indies and Mexico are subject to question.

## THE GENUS NEASPILOTA OSTEN-SACKEN

*Adult.*—Head with vertex approximately as broad as maximum width of eye; frons strongly tapered, sunken below ocellar triangle, strongly projecting near bases of antennae; third antennal joint more or less lobate, with a tendency toward a distal angulation; all bristles of the head and thorax yellow or yellowish brown, but not of a scalelike nature, except as otherwise mentioned; three pairs of frontal bristles; two pairs of upper orbitals, the upper pair as strong as the lower pair but nearly reclinate and converging; one pair of long ocellar bristles; occipitals pale and scalelike; inner and outer verticals long; postocular cilia scalelike but not weak; cheek bristle long, well defined; cheek cilia conspicuous. Thoracic dorsum finely pollinose in appearance, clothed with pale scalelike hairs; dorsocentral bristles remote from suture but only slightly behind line of anterior supraalars; scutellum with two pairs of long bristles. Abdomen, exclusive of the ovipositor sheath, approximately equal in length to thorax. Ovipositor sheath broad, but as long or longer than the two preceding abdominal segments. Male genitalia with the forceps curved toward each other, the internal process armed with two small teeth. Wing with the first vein strongly spined; with no trace of spines on the third vein, or on the knot at the junction of the second and third veins, either on the upper or the under side of the wing; anterior cross vein beyond the middle of the relatively long distal cell, at about the beginning of the distal third of that cell in most of the species; anal cell produced to a short point on sixth vein.

Type of the genus, *Trypeta alba* Loew.

The generic name *Neaspilota* was first proposed by Osten-Sacken (*66, p. 192*) in 1878 for a subgenus of *Trypeta* without designation of genotype, and as a new name to replace *Aspilota* Loew. The latter was described by Loew (*60, p. 286*) in 1873, but is preoccupied by *Aspilota* Foerster, 1862, a generic name in Hymenoptera. Coquillett (*14, pp. 511, 574*) designated *Trypeta alba* Loew genotype of *Neaspilota* Osten-Sacken and *Aspilota* Loew (not Foerster). Williston (*99, pp. 285, 287*), and Hendel (*35, p. 92; 36, p. 7*) spelled the name *Neoaspilota*. The genus has been discussed under the name *Neaspilota* by a number of authors, including Aldrich (*2, p. 610*), Cresson (*16, p. 276*), Phillips (*69, p. 139*), Curran (*22, p. 3*), and others.

With the exception of *vernoniae* Loew, which is atypical on several characters, and *achilleae* Johnson, which is structurally typical but easily distinguished by the dark markings on the wings, the genus contains a number of closely related species. These are extemely difficult to sort, and there are probably several more species than names.

There exist in Florida, and presumably elsewhere, two or more species with larvae which have 3 or 4 beads on each anterior spiracle, the caudal ends individually tending to become more or less blackened or powdered with black before the larvae form puparia, and otherwise practically identical, except in size, which is directly proportionate to that of the corresponding adults. This group is divisible on the stigma, forming two subgroups, one of which possesses a conspicuous black patch occupying the proximal part of the stigma, the other having the stigma ranging from nearly clear yellowish brown to suffused with brownish or fuscous in the proximal part. Corresponding with the heavily black-marked stigma, the abdomen has the ground color so marked with fuscous that at least on segments 2 to 4, inclusive, of the males and 2 to 5, inclusive, of the females, dorsally only a narrow strip of the yellowish ground color distally crosses each seg-

ment. Corresponding with the less heavily marked stigma the abdomen has the black which suffuses the ground color restricted to the proximal parts of segments 2 to 4 or 2 to 5. This abdominal character can be seen only in specimens which have been moistened or are greasy; all specimens have the abdomens heavily powdered with pollinose, so an abdomen which is heavily black marked appears mainly brownish or yellowish with the distal margins of the segments narrowly and disconcolorously lemon yellow; an abdomen with the fuscous suffusion limited to the proximal parts of the segments appears a brighter yellow, the distal margins of the segments being broadly and disconcolorously lemon yellow.

Specimens which have been killed before attaining complete coloration often appear to represent distinct species. Some of these, which would later have the darkly marked stigma and dark abdomens, may easily be mistaken for specimens belonging to the paler subgroup. These immature specimens have the abdomens usually brighter yellow with the dark markings only faintly visible, the stigma usually hyaline or nearly so.

To further complicate the situation, pinned specimens soon become greasy and much darkened, and the usual run of material found in collections is of this kind. Fully matured individuals which have obtained complete coloration are much more active in the field than the incompletely colored, adolescent individuals, so the latter are more easily caught and form a part of each collected series. Size, as a character, is of small value, except to sort the large and atypical *vernoniae* from the remainder of the genus, and even that species is probably more subject to variation in size than indicated in most collections. The size of the specimens of a series depends largely upon the kind and condition of the host, and specimens far smaller than normal for a given host are often reared because of drying of the food. The exact length of portions of veins, such as the terminal part of the fourth vein in relation to the length of the discal cell, a character used by some authors to place *vernoniae* in a different genus, is subject to much individual variation in bred series from the same host and which are obviously otherwise similar. The exact shape of the wing is subject to variation, especially within bred series, partly because of a tendency for specimens which are undernourished to develop shorter wings and more or less distorted costal margins, but also partly because the smallest individuals have wings which appear to be porportionately more reduced in width across the axillary region than in length, thus causing what at first seems to be quite distinct species on this character. Specimens which are small because of having fed as larvae within flowers of some plant such as *Erigeron*, usually have the frons much sunken and appear to have a head shape quite distinct from that of normal specimens from some of the larger host flowers. But intermittently, throughout series reared from some of the larger flowers, specimens are obtained which have heads similar to those of specimens from some of the smaller flowers; and apparently such specimens may be obtained by making the food unsuited, by drying or otherwise, for complete development to the adult. Specimens from any single locality and single species of host tend to form colonies which may be sorted by slight differences in wing shape, amount of black in the stigma, and amount of black marking the abdominal segments, with the result that several "species" might easily be named.

But these "species" often seem to intergrade completely when several series are obtained from the same host but from slightly different localities; also, when several series are obtained from similar, but distinct, species of hosts, such as, for example, the different species of *Chrysopsis*.

The male genitalia are comparatively soft and easily distorted so that if examined on a few specimens they often seem to present specific differences, yet these apparent differences also seem to exist between otherwise identical specimens from a single host.

In short, from nearly 1,000 specimens reared from known hosts, the author was unable to select any character or set of characters based either on adult or immature stages which seemed stable enough to serve as a basis on which to split the series into more than two parts, although if parts of each series were discarded, several "species" would seem indicated.

A key is given which will aid in separating the described species, but it will serve only for typical and matured specimens which are neither stained nor greasy:

*Key to species of Neaspilota*

1. Wing with black markings on the disk in addition to black in the stigma.. 2.
   Wing without black markings, or with the marking restricted to the stigma. 3.
2. Size large, wing measuring more than 4 mm in length; the black on the wing reaching the apex of the fourth vein; the polished spot on the thorax in back of the head brownish..... **vernoniae** Loew.
   Size smaller, wing measuring less than 4 mm in length; the black on the wing not reaching the apex of the fourth vein; the polished spot on the thorax jet black..... **achilleae** Johnson.
3. Abdomen uniformly purple-black, and with dark brownish or black vestiture; wing with the entire stigma dark fuscous brown or black **albidipennis** Loew.
   Abdomen with a luteous or brownish ground color which is at least indicated on the apical margins of the segments, the abdominal vestiture with many pale hairs or scalelike hairs; wing with the stigma variously marked or unmarked, but not entirely dark fuscous brown or black..... 4.
4. Mature specimens with the stigma nearly hyaline, pale yellowish unmarked by brown or black; side of the thorax between the spiracle and the base of the wing (the mesopleura) fuscous, pollinose, and appearing of a gray color; larvae and puparia curved, each anterior spiracle usually with 6 or 7 beads; only known host, flowers of *Vernonia* sp..... **alba.**
   Mature specimens with the stigma usually disconcolorous, either brownish, or fuscous, or marked with a spot; if the stigma is apparently nearly hyaline, the mesopleura appears bright yellow or lemon yellow, not fuscous overpowdered with pollinose and appearing gray; larvae and puparia [where known] not conspicuously curved, each anterior spiracle with about 3 or 4 beads; hosts, flowers of various composites..... 5.
5. Cross veins and tips of some of the longitudinal veins dark brown, disconcolorous with the luteous or lemon-yellow parts of the veins..... 6.
   Cross veins and longitudinal veins uniformly bright luteous or lemon yellow..... 7.
6. Stigma appearing nearly uniformly brown..... **brunneostigmata** Doane.
   Stigma with a large proximal fuscous-brown or blackish spot contrasting with the pale yellowish almost entirely hyaline distal area **signifera** Coquillett.
7. Stigma with a large jet black proximal spot in contrast to an almost hyaline distal area..... **punctistigma,** new species.
   Stigma with the proximal part brownish, occasionally powdered with grayish black, often appearing almost entirely hyaline..... **dolosa,** new species.

### NEASPILOTA ACHILLEAE Johnson

(Fig. 26, *A–L*)

Described as *Neaspilota achilleae* by Johnson (*46, p. 328*) in 1900 and subsequently discussed by Johnson in several papers which added little excepting additional localities. Phillips (*69, p. 140*), in 1923, used the spelling "*achilliae*."

*Adult.*—Head, including the antennae, lemon yellow, paler near the mouth and eyes. Thoracic ground color bright lemon yellow; dorsum with a conspicuous polished black spot directly behind the head, with the mesothoracic ground color largely replaced by black, which in fresh specimens appears a pollinose silvery gray, extending in four tonguelike prolongations toward the scutellum, but leaving all of the long bristles on the yellow ground; otherwise, the thorax largely yellow marked by bright lemon yellow, and with gray-black, of the same nature as that on the dorsum, marking the metathorax and the areas between the coxae; scutellum lemon yellow, dorsally with a faint silvery-gray tinge. Legs yellow. Abdomen yellow, nearly unicolorous with the exception of the slightly more rufous ovipositor sheath, which is darkened at the tip. Any or all of the yellow of the head, antennae, legs, thorax, and abdomen tending to appear more or less tinged with rufous in all specimens with the exception of those which have been freshly killed. Wing hyaline, with a jet-black patch occupying the basal part of the stigma; and smoky-black markings as illustrated, these markings tending toward reticulation; the posterior margin not subparallel with the costa. Size: Male wing about 2.5 to 3.6 mm by 1.1 to 1.6 mm, female wing about 2.5 to 3.8 mm by 1.1 to 1.7 mm. Length of male 2.8 to 3.1 mm, of female 2.8 to 3.3 mm.

*Immature stages.*—Larva about 3.2 to 3.8 mm in length and 1.25 to 1.5 mm in diameter, usually slightly curved, white, with the caudal end often blackened, especially before forming the puparium; the skin appearing relatively smooth, but covered by a fine stippling of granular spines; anterior spiracles usually with about 3 or 4 beads; posterior spiracles close together, the slits on each spiracle elongate, straight sided, and subparallel, on obsolescent plates with more strongly chitinized plates showing through from below. Puparium about 3.1 mm in length by 1.4 to 1.6 mm in diameter; more or less ovate (not bean-shaped as in *N. alba*); the skin white or whitish, and translucent, the contained pupa creating a straw-colored appearance; the caudal end often blackened; the segmental sutures defined.

*Hosts.*—The larvae feed singly in the flowers of a large number of different composites. The preferred hosts in Florida seem to be various species of *Hieracium.* Adults were reared from *H. argyraeum, H. grovonii, H. scabrum,* and more rarely from *Sericocarpus acutisquamosus, Aster carolinianus, A. concolor, Chrysopsis latifolia, C. microcephala, C. oligantha, Erigeron ramosus,* and *E. vernus.*

*Distribution.*—The species seems generally distributed and abundant throughout at least the northern half of Florida. Previously published records cite Massachusetts, Pennsylvania, New Jersey, Georgia, and northern Florida.

### NEASPILOTA ALBA (Loew)

(Fig. 27, *A–M*)

Described as *Trypeta alba* (*56, p. 345*) by Loew in 1861, and included in the Loew papers of 1862 (*57, p. 100*) and 1873 (*60, p. 285*), in the latter placed in the subgenus *Aspilota.* Osten-Sacken (*66, pp. 192, 260*), in 1878, placed the species in the subgenus *Neaspilota,* and records the larvae as living in the buds of *Vernonia.* The species has since been discussed by a number of authors, and consistently placed in *Neaspilota.*

*Adult.*—Head, including the antennae, yellowish, more or less tinted with ferruginous, paler near the mouth and eyes. Marking on the thoracic dorsum similar to that described for *N. achilleae*, with the black somewhat more extended, the yellowish lacking the lemon cast, and so tinted with fuscous that in conjunction with the general pollinose effect the yellow dorsal parts appear almost silvery gray, the coloration extending onto most of the dorsum of the scutellum to a greater degree than in *achilleae;* similar silvery gray also obscuring the yellow of most of the lateral margins of the notum and the pleurae, especially the mesopleurae. Legs ferruginous yellow. Abdomen more ovate than in *N. punctistigma* and *N. dolosa*, ferruginous yellow with brownish or blackish bands occupying much of the dorsal parts of the segments, the yellow ground color showing laterally, and as terminal bands on all segments, only the first abdominal segment and the ovipositor sheath being more or less conspicuously yellowish. Ovipositor sheath relatively short and broad, only slightly longer than the two preceding abdominal segments. Wing, with the exception of the yellow veins and the very pale granular yellowish stigma, entirely hyaline; posterior margin oblique, not subparallel with costa. Size: Male wing about 3.4 by 1.6 mm, female wing 4 by 1.9 mm. Length of male 3.3 to 3.5 mm, of female 3.5 to 4 mm.

*Immature stages.*—Larva about 4 mm in length and 1.2 mm in diameter, curved, so that the midventral line is longer than the middorsal, white, with the caudal end not blackened; skin appearing relatively smooth, but covered by a fine stippling of granular spines; anterior spiracles usually with 6 or 7 beads; posterior spiracles close together; the slits on each spiracle elongate, straight sided, and subparallel, on obsolescent plates, strongly chitinized plates showing through from below. Puparium somewhat shorter than a corresponding larva, but of approximately the same diameter; the skin white or whitish and translucent, the contained pupa creating a straw-colored appearance; shape similar to that of the larva, curved; segmental sutures plainly defined.

*Hosts.*—The larvae feed in the flowers of various species of ironweeds, *Vernonia,* including *V. scaberrima, V. gigantea,* and *V. blodgetti.*

*Distribution.*—The species seems generally distributed throughout Florida, and probably is present wherever its hosts grow in that State. The species was described from Pennsylvania, and has been recorded from Massachusetts, Rhode Island, New York, and New Jersey, also from Missouri, Colorado, and New Mexico. At least some of the records are subject to suspicion, as the various species in the genus have been much confused.

*Note.*—Florida specimens were compared by the author with the Loew types in the Museum of Comparative Zoology and appear to agree in all details. The figures and descriptions were made from Florida specimens reared from *Vernonia scaberrima.*

### NEASPILOTA PUNCTISTIGMA, new species

(Fig. 28, *A–L*)

This apparently is the species listed as *Neaspilota signifera* Coquillett by Johnson (*52, p. 84*) in 1913.

*Adult.*—Head, including the antennae, yellowish, more or less tinted with ferruginous and with lemon yellow, paler and often grayish near eyes and mouth, frons often sunken on small specimens, and usually either flattened or slightly excurved on larger specimens, regardless of the host. Thorax colored and marked much like that of *N. achilleae,* the pleurae sometimes slightly tinged with silvery gray. Legs yellow, often tinged with lemon yellow. Abdomen more tapered and less ovate than that of *N. alba,* with a lemon-yellow ground color, but dorsally so heavily marked with transverse black bands and the whole so pollinose as to present the appearance of a brownish or yellowish abdomen with the distal margins of the segments narrowly and disconcolorously bright lemon yellow; ground colors visible in presence of grease, the yellows appearing tinted with ferruginous. Ovipositor sheath as long or longer than the three preceding segments; luteous brown or rufous brown, with a darker tip; the ovipositor showing through the thin chitin and causing the appearance of a dark longitudinal streak. Wing entirely hyaline, except for the yellow or lemon-yellow veins, and the

stigma, which normally is yellowish with a conspicuous jet-black proximal spot, but which may be nearly hyaline in occasional specimens which have been killed before attaining complete coloration. Size: Variable, largely dependent upon both the species and the quality of the host. Among the smallest specimens are a female from *Pluchea imbricata*, with a length of 1.8 mm and a wing 1.9 by 0.7 mm, and a male from the same lot with a length of 2 mm and a wing 2.1 by 0.8 mm—obviously undersized examples. Most of the specimens from *Pluchea* with a length of about 2.5 mm for the males and the females about 0.1 to 0.25 mm longer, the wings much the same in the two sexes, about 2.3 to 2.4 mm by 1 mm, those of the females possibly averaging very slightly longer and broader than those of the males; the transition in size gradual to the largest specimens, from *Sericocarpus*, one abnormally large female from the latter host having a length of 3 mm and a wing measuring 3.2 by 1.3 mm. Specimens from various species of *Chrysopsis* intermediate in size between the extremes.

*Immature stages.*—The larvae and puparia, which vary in size proportionately with the corresponding adults, are practically identical with those of *achilleae*.

*Hosts.*—The larvae feed singly in the flowers of various composites, and adults were reared from the following: *Pluchea foetida*, *P. imbricata*, *Chrysopsis* sp., *C. hyssopifolia*, *C. microcephala*, *C. mariana*, *C. traceyi*, *C. trichophylla*, *Sericocarpus acutisquamosus*, and *S. bifoliatus*. A single specimen was apparently reared from a flower of *Lantana sellowiana* but the record needs vertification, as the adult may simply have been hidden within the flower.

*Distribution.*—Generally distributed and abundant throughout Florida, and probably in at least some others of the Southern and Eastern States.

*Types.*—To avoid the chance of a mixed-type series, the types are restricted to specimens reared from *Pluchea foetida*. Holotype male from 4 miles east of Fort Christmas, Fla., June 14, 1930; allotype female, from same lot, June 17, 1930. Seventy paratypes, about evenly divided as to sex, from the following Florida localities: 4 miles east of Fort Christmas, Fort Christmas, Bithlo, Oviedo, Orlando, Longwood, Branchboro, Cleveland, Wiersdale, Caryville, Forest City, Conway, and from Brevard County.

*Note.*—Specimens from *Pluchea foetida* and from *P. imbricata* were considered in the field as probably representing a species distinct from the feeder in *Chrysopsis* and in *Sericocarpus*, but this point must be held in abeyance, as the author is unable to find characters to differentiate the latter.

### NEASPILOTA DOLOSA, new species

(Fig. 29, *A–L*)

Another species which the writer considers as new has been classed with *Neaspilota alba* Loew in some collections.

*Adult.*—Similar to that of *N. punctistigma*, with the following exceptions: Pleurae seldom, if ever, tinged with silvery gray; abdomen with a lemon-yellow ground color, but dorsally marked with transverse black bands only on the proximal parts of segments 2 to 4 in the male and 2 to 5 in the female, which, in conjunction with the pollinosity, creates the appearance of a luteous abdomen with the segments distally bright lemon yellow and proximally rufous brown. Stigma with the proximal part brownish, occasionally powdered with grayish black, or often appearing almost entirely hyaline. Size: Largely dependent upon the condition of the host; male ranging from about 2 to 2.8 mm in length and with a wing measuring 2 to 2.8 mm in length and 0.9 to 1.1 mm in width; female with a length of from 2.6 to 3.4 mm and a wing measuring 2.1 to 2.8 mm by 1 to 1.1 mm.

*Immature stages.*—The larvae and puparia, which vary in size proportionately with the corresponding adults, are practically identical with those of *achilleae;* and differ by usually having, instead of often having, the terminal segment

distinctly black marked, the black often extending dorsally onto the preceding two segments.

*Host.*—The larvae feed singly in the flowers of *Heterotheca subaxillaris.*

*Distribution.*—Reared from the following Florida localities: Orlando, near Orlando, Forest City, Lockhart, Mount Dora, Leesburg, Wiersdale, Belleview, Clermont, Fairvilla, Rocky Point, Cocoa, and New Port Richey.

*Types.*—Holotype male, Orlando, Fla., June 10, 1930; allotype female, same lot, June 14, 1930. One hundred and fifty paratypes about equally divided as to sex from the above-named localities.

*Notes.*—Short series reared from *Sideranthus megacephalus* and from *Erigeron vernus* and *E. ramosus* may be conspecific. Specimens of the first-mentioned average somewhat larger than those from *Heterotheca* and each has the stigma as pale as that of *N. alba*, but the body shape, the length of the ovipositor sheath, and the coloration definitely link the series with *dolosa* and separate it from *alba*. There is, also, some possibility that these specimens are immature examples of *punctistigma*, but the generally firm and matured appearance of the chitin almost precludes this possibility. The specimens from both species of *Erigeron* form a relatively compact unit, averaging smaller than those from *Heterotheca*, and with the stigmae, on the average, somewhat more contrastingly marked, smoky black being frequently present basally. Possibly this is only the result of a different food.

## THE GENUS PAROXYNA HENDEL

*Adult.*—Head with vertex approximately as broad as maximum width of eye; frons tapered, strongly produced near antennae; third antennal joint slightly pointed; tongue very long and geniculate; head bristles black excepting as otherwise noted; 2 pairs of frontal bristles; a few deciduous pale cilia on each side of the front near the eyes; 2 pairs of upper orbital bristles, the upper pair pale and scalelike; 1 pair of ocellar bristles; inner verticals long and strong; outer verticals long, but pale and scalelike; occipitals pale, scalelike, scarcely divergent; postocular cilia often consisting mainly of short, black bristles, but with at east 2 pale scalelike bristles behind each eye; cheek cilia short and pale, the cheek bristle relatively strong, but caudad of the usual position in the group and inconspicuous. Thoracic dorsum clothed with pale, nearly scalelike hairs extending onto the scutellum; dorsocentral bristles in front of line of anterior supraalars and nearly on the suture; scutellum with one pair of strong bristles and usually with an additional posterior pair of bristles which may be short and black or pale and scalelike, the character of specific significance. Abdomen, exclusive of the ovipositor sheath, about as long as the thorax, dorsally clothed with pale scalelike hairs intermixed with darker short bristles, with conspicuous macrochaetae on last segment of male and on fourth and fifth segments of female; ovipositor sheath sparsely clothed with fine dark hairs, flattened, relatively broad, as long as preceding 2 or 3 segments. The male genitalia indicate two groups, possibly subgenera, and are discussed under the specific headings. Wing hyaline, with a dark reticulate design; first vein spined; third vein naked; anterior cross vein from near beginning of distal third of long discal cell; anal cell drawn out to a short point on sixth vein.

Type of the genus, *Trypeta tessellata* Loew.

The generic name *Paroxyna* was first proposed by Hendel (*37, pp. 23, 146*) in 1927, with *tessellata* Loew designated as type. The genus includes *Oxyna*, in part, of *Loew* (*59, p. 85*) and other European workers and *Ensina* of papers on American trypetids.

The genus belongs with a group, including the genera *Ensina* Robineau-Desvoidy and *Oxyna* Robineau-Desvoidy, the species of which all possess long geniculate tongues. Ultimately some generic lumping may be necessary. *Ensina*, as exemplified by *E. sonchi* Linnaeus,

has 4 strong scutellar bristles and 3 pairs of frontals. All of the specimens before the writer lack the dorsal pair of upper orb tal bristles, but have a wing pattern and a habitus suggestive of *Neaspilota achilleae*. The genus *Neaspilota* does have characters in common with this long-tongued group. The general absence of spines on both under and upper sides of the wing on the third vein is one such character. Others may be seen by a comparison of the biologies and immature stages of *Ensina picciola* with those of the various species of *Neaspilota*.

#### PAROXYNA THOMAE (Curran)

(Fig. 37, *A–G*)

*Ensina thomae* was described by Curran (*20, p. 70, fig. 30*) in 1928 from a unique female type, now in very bad condition, in the American Museum of Natural History. The specimen seems to have been killed before gaining complete coloration, but the remnants of the wings appear to have more markings than shown in the original figure, which conveys an erroneous impression.

The Florida specimens here described were compared with the type of *thomae* by the author, who was unable to discern any specific distinction. Better specimens from St. Thomas must be awaited before the Florida species can be stated, with any certainty, to be conspecific. Nevertheless, agreement was noted on several specific characters, viz, the yellow apex of the scutellum, the somewhat longer ovipositor sheath, the dark coloration on the posterior femora, and the general pattern of the wing including the lack of a hyaline droplet above the termination of the second vein, and the style and extent of the apical dark markings. Williston's figure labeled *peregrina* Loew (*98, p. 377, pl. 13, fig. 130*) from St. Vincent, and subsequently published without specific name (*99, p. 285, fig. 24*) is probably the same species.

*Adult.*—Head yellowish in frontal view, antennae and lower part of the frons darker, almost rufous-orange, eyes surrounded by whitish, back of head fuscous. Thorax black, pollinose with yellowish and orange, and appearing gray, with longitudinal bands, more or less defined, one on each side of center of dorsum at bases of dorsocentral bristles, and a short similar band on each side of mesonotum at bases of presutural bristles; scutellum with a distinctly pale yellowish apical area, with 2 strong, dark anterior bristles, and with 2 short, weak, posterior bristles which are usually pale, deciduous, and scalelike (as a short, black bristle on one side, and as a pale scalelike hair on the other side, of the scutellum of a single specimen). Legs variable in coloration, luteous brown, sometimes with a rufous tinge, outer sides of femora, especially of hind legs, darker. Abdomen black, pollinose, appearing gray, a longitudinal band of dark patches on each side of center. Ovipositor sheath black. Male genitalia with ring of second male genital segment much enlarged, not retracted or hidden beneath the body, but visible as if it were a terminal appendage, of the peculiar shape illustrated in figure 37, *C* and *D*, and armed with strong, short, spinelike hairs; forceps practically invisible except from below, curved toward each other from near the proximoventral angles, each of the forceps bearing the usual internal process armed with teeth. Wing hyaline, with a reticulate black design, individually somewhat variable in extent and density, especially in second and third posterior cells, and surrounding the apical hyaline spot in first posterior cell, also with or without from 1 to 3 hyaline droplets interrupting the black subapical patch in submarginal cell. Size: Wing about 2.8 mm by 0.9 to 0.95 mm, the males frequently somewhat smaller, the females sometimes somewhat larger, but a sexual difference in size of wing not pronounced in normally developed individuals. Normal length of male 2.75 to 3 mm, of female 3 to 3.25 mm.

*Immature stages.*—Not differentiated from those of the related and much more abundant *Paroxyna picciola* Bigot.

*Host.*—The species was reared in quantity, but only from the flowers of *Bidens bipinnata*.

*Distribution.*—The only flowers of *Bidens bipinnata* collected were from Orlando, Oviedo, and Crystal River, Fla., and adult flies were obtained from these flowers. The Curran type is stated to have come from the Island of St. Thomas, West Indies.

### PAROXYNA PICCIOLA (Bigot)

(Fig. 30, *A–N*)

Described as *Acinia picciola* by Bigot (*8, p. 347*) in 1856. The description and figure are unrecognizable, but the identity was established by Loew (*60, pp. 291, 337*) in 1873. *Trypeta humilis* Loew, described (*57, p. 81*) in 1862, and *Trypeta aurifera* Thomson, described (*88, p. 585*) in 1868, appear to be synonymous. Loew, in 1873 (*60, pp. 291, 337*), and Osten-Sacken, in 1878 (*66, p. 193*), placed the species in *Ensina* as a subgenus of *Trypeta*. Coquillett, 1899 (*13, p. 264* , used the generic name *Tephritis*. Since that date the species has quite generally been placed in *Ensina*. Hendel (*36, p. 65*), in 1914, listed the species as a synonym of *chilensis* Macquart (*61, p. 387*). None of the Florida series agrees with Hendel's figure.

*Adult.*—Head in frontal view and including antennae rufous, eyes surrounded by whitish, back of head fuscous. Thorax black, pollinose with yellowish, fresh specimens appearing luteous to luteous gray, with more or less obsolescent longitudinal bands; scutellum concolorous with remainder of thorax and lacking any trace of apical yellowish ground color, with two strong, dark, anterior bristles, and with two short, dark, weak, but distinct, posterior bristles. Legs variable in coloration, luteous brown, sometimes with almost a rufous tinge, usually somewhat darkened with fuscous, especially on outer sides of femora, which are quite disconcolorous. Abdomen black, pollinose, appearing gray, a longitudinal band of dark patches on each side of center. Ovipositor sheath black. Male genitalia with ring of second male genital segment narrowed to form the forceps, which are bent toward each other in a manner normal in the group; the internal process of the usual pattern, with two strong teeth; the entire genitalia partly fitting beneath the last abdominal segment in almost the usual manner, and as illustrated in figure 30, *J*. Wing hyaline, with a reticulate black design individually somewhat variable in extent and density. Size: Wing of male about 2.2 to 2.5 mm by 0.8 to 0.9 mm, of female 2.5 to 2.6 mm by 0.9 to 1 mm. Normal length of male 2.1 to 2.5 mm, of female 2.5 to 3 mm.

*Immature stages.*—Larva white; 2.5 to 2.75 mm in length and 0.8 mm in diameter; skin appearing relatively smooth, but covered with a stippling of fine spines; each anterior spiracle with about five beads; posterior spiracles close together, the slits on each spiracle elongate, straight sided, and subparallel, on obsolescent plates, more strongly chitinized plates showing through from below. Puparium only very slightly shorter and broader than a corresponding larva; of a color ranging between straw and pale brown; with most of the segmental sutures poorly defined.

*Hosts.*—The larvae feed in the flowers of many composites, and adults were reared in quantities from the flowers of *Bidens leucantha*, and more rarely from the flowers of *B. bipinnata*, *B. laevis*, *Actinospermum angustifolium*, *Coreopsis nudata*, *C. leavenworthii*, *C. tripteris*, *Tagetes erecta*, and *Cosmos* sp.

*Distribution.*—Vying with *Xanthaciura insecta* as the most generally distributed and abundant Florida trypetid. The Bigot and the Loew types of *P. picciola* are recorded as coming from Cuba. The Thomson types are supposedly from California. The species seems generally distributed throughout the Gulf States, but has been recorded also from Tennessee, Illinois, Iowa, Kansas, South Dakota, and Colorado, and also from Bermuda, Bahama Islands, Cuba, Puerto Rico, Jamaica, Mexico, and South America. Some of the records probably refer to closely related but distinct species.

## THE GENUS XANTHACIURA HENDEL

*Adult.*—Head with vertex narrower than maximum width of eye; frons somewhat tapered and flattened, often sunken except approaching bases of antennae; third antennal joint relatively long, apex rounded; three pairs of blackish frontal bristles; with two rows of pale deciduous scalelike hairs, one row on each side of front near each eye; two pairs of upper orbitals, the upper pair small, palé, and scalelike, lower pair strong and dark; one pair of long, strong, dark, ocellar bristles; occipitals weak, pale, scalelike, poorly defined from the postocular cilia, parallel, and obliquely extending in a caudal direction; inner verticals very long, strong, dark, nearly parallel and recurved; outer verticals usually stronger and darker than postocular cilia; the latter scalelike, pale, relatively strong, and extending in a generally caudal direction; cheek bristle relatively strong, pale, but not scalelike; cheek cilia pale. Thoracic dorsum clothed with deciduous, pale, scalelike hairs, the anterior pair of supraalar bristles relatively caudad owing to the strong curvature of the suture, the dorsocentrals well in front of the supraalars and almost on the line of the suture, the acrostichals farther forward than usual in the family; scutellum with either 1 or 2 pairs of bristles and some pale scalelike hairs. Abdomen, exclusive of the ovipositor sheath, approximately equal in length to the thorax; ovipositor sheath short and broad; male genitalia of two different kinds as illustrated (fig. 31, *K* and *L*; compare with figs. 32, *H* and *I*, and 33, *H* and *I*), possibly indicative of two subgenera. Wing with the first vein strongly spined; second vein often uneven in its course; third vein, and the knob at its base, spined to near or just beyond the anterior cross vein, spines difficult to see, weak, and deciduous; anterior cross vein distad of middle of discal cell; anal cell nearly truncate, not produced along sixth vein and only slightly pointed.

Type of the genus, *Trypeta chrysura* Thomson.

The generic name *Xanthaciura* was proposed by Hendel (*35, p. 86*) in 1914 in a key, with *chrysura* Thomson the sole species and designated genotype. Later in the same year the same author again published (*36, pp. 7, 46*) the name *Xanthaciura* as a new generic name with *chrysura* designated genotype. The generic name *Tetraciura* Hendel was also proposed (*35, p. 90*) in the same key with *Xanthaciura* and also, as with the latter, again published (*36, pp. 7, 48*) as a new generic name later in the same year. A description accompanied each of the names in the second paper. *Xanthaciura* is based on species with the scutellum two-bristled, while *Tetraciura* is based on a single species with a four-bristled scutellum. The character is not of generic significance within this group.[6] *Tetraciura* is, therefore, placed as a synonym. Phillips (*69, p. 131*), in 1923, erected, under the genus *Aciura*, the subgenus *Eucosmoptera* for three species, *nigricornis* Doane, *limata* Coquillett, and *tetraspina* Phillips, without designation of type. The first species, *nigricornis*, violates the characters assigned by the author to *Aciura* by having the dorsocentral bristles well behind the line of the anterior supraalars. It also practically falls into the category of a *species inquirenda*, and, therefore, should not be designated genotype (*86, p. 26*). The second species, *limata*, was unknown to the author of *Eucosmoptera*, except through information derived from the original description of that species and a drawing of the type specimen. It also violates the characters assigned to *Aciura* by having the dorsocentral bristles well behind the line of the anterior supraalars. Therefore it cannot logically be selected as the type of *Eucosmoptera*. The species is treated on p. 21 and assigned to the genus *Myoleja* Walker. This leaves *tetra-*

[6] The biology, including the hosts, the shapes and the structures of the larvae, and the male genitalia, and the general habitus of the adults all show *X. connexionis* and *X. tetraspina* more closely related to each other than either are to *insecta*. Possibly a subgeneric division is indicated, but not based on the number of bristles on the scutellum. The taxonomic value of the number of scutellar bristles appears to vary with the group. In many instances these bristles furnish a superficial character assisting in the sorting of groups or of genera. In other instances, as with *Eurosta comma* Wiedemann, differences in the number of scutellar bristles are not of specific significance.

*spina* as the sole species in the subgenus *Eucosmoptera* agreeing with the generic characters assigned by Phillips to *Aciura*, and also as being the only species definitely and certainly known to the author of *Eucosmoptera*. But *tetraspina* has a truncate anal cell and thereby violates the description given under *Eucosmoptera*. In short, no species assigned by the author to the subgenus will logically serve as the type, yet a type must be selected if the name is to be restricted so that it is available for one of its component parts. Therefore the name best known to the author of *Eucosmoptera*, and the one which will cause the subgeneric name to be associated with the *Aciura* complex, *tetraspina* Phillips, is hereby designated the type. This selection causes the name *Eucosmoptera* to become a synonym of *Xanthaciura* for the reasons cited under the discussion of the name *Tetraciura* Hendel. Curran (*22, pp. 4, 12*), in 1932, used the name *Eucosmoptera* Phillips as a generic name, without designation of genotype, and included only the same three originally assigned species. Several authors have shown that the European genus *Aciura* Robineau-Desvoidy (*70, p. 773*), proposed in 1830, with genotype *Acinia femoralis* Robineau-Desvoidy by designation of Rondani (*72, p. 113*) in 1856, will not serve for the related American species. The genus *Aciura*, in the restricted sense, is discussed by Hendel (*37, p. 108*). The name *Xanthaciura* appears to be the oldest valid name for *Aciura* as used for American species by Loew (*60, p. 268*). The name *Aciura* as used by other authors dealing with American material prior to 1914 presents a badly mixed lumping of species representing several genera some of which, in the larvae, feed in fruits. The known larvae of *Xanthaciura* all feed in composite flowers.

### XANTHACIURA INSECTA (Loew)

(Fig. 31, *A–O*)

Described as *Trypeta insecta* by Loew (*57, p. 72*) in 1862.

*Adult.*—Head, including the antennae, yellowish. Thorax black dorsally, laterally brownish black, ventrally yellow; scutellum black. Legs yellow. Abdomen yellow, sometimes strongly tinged with brown and blackish brown, which tends to darken the dorsum of the last one or two abdominal segments of the male, or to form two bands on the female, one including the distal half of the second abdominal segment with the third and fourth abdominal segments, the other darkening the tip of the yellow ovipositor sheath. Male forceps not conspicuously incurved, but each bearing a long, pointed, oblique projection (fig. 31, *L*), and a distal, short, heavily setulose lobe; internal process long and excurved, the normal two teeth practically fused into a chitinous pad. Wing nearly covered by a black pattern; with three hyaline spots in the costal cell, one being before the humeral vein; with two large, triangular, hyaline areas, extending from the costa through the first marginal cell and terminating in the submarginal cell; a small, round, hyaline spot in the first basal cell; two similar spots in the first posterior cell; six hyaline incisions along the posterior margin, the proximal two coalescing with the hyaline axillary area; the second vein uneven in its course. Size: Male wing 2.6 by 1.1 mm, female wing 3.2 by 1.2 mm. Length of male 2.9 to 3 mm, of female 4 mm.

*Immature stages.*—Egg white, ovate, with a small point on one end. Larva about 4 mm in length and 1.4 mm in diameter, white, with the caudal end truncate and blackened; skin quite generally covered with minute spines arranged in irregular and interrupted rows around the body, becoming obsolescent on first segment and upon caudal half of second segment; anterior spiracles averaging five beads each; posterior spiracles widely separated, the slits short, broad, and semiovate, those on each spiracle arranged in a fan with the distal ends widely separated. Puparium about 2.75 mm in length and 1.4 mm in diameter, brown-

ish straw colored, with the caudal end truncate and black, the segmental sutures more or less defined

*Host.*—The larvae feed in the flowers of white sticktight, *Bidens leucantha*, an abundant and pernicious weed.

*Distribution.*—The species is abundant throughout Florida, and has been recorded from Bermuda, the Bahamas, and various of the West Indian Islands; also from Mexico and South America, but these latter records will need verification, as there are a number of closely related tropical species.

### XANTHACIURA CONNEXIONIS, new species

(Fig. 32, *A–L*)

*Adult.*—Similar to *X. insecta* (Loew) and agreeing with that species in having the ventral part of the thorax yellow, and in having a 2-bristled scutellum. Differing therefrom by being smaller in size, the abdomen bright rufous yellowish; the male possessing conspicuous dorsal black marking which covers the two terminal segments and part of the preceding; the female with a spot covering most of the dorsum of the last three and one half segments, exclusive of the ovipositor sheath, which is bright rufous yellowish with a black tip. Male genitalia almost identical with those of *tetraspina*, thus differing greatly from those of *insecta*. Wing marked in a manner similar to the wings of *insecta* and *tetraspina*, with the posterior margin as in the latter, the discal cell as in the former, and differing from both by lacking the hyaline droplet in the first basal cell. Easily distinguished from all known species of the genus by the second vein being much shorter than normal, waved, with two noticeable bends toward the third vein, then with the apical portion conspicuously oblique to the costa. The species acts as a connecting link between the *insecta* series (*Xanthaciura*) and the *tetraspina* series (*Tetraciura*), as it has a 2-bristled scutellum like the former, but the male genitalia and the immature stages much like those of the latter. Size: Male wing 2.1 by 0.8 mm, female wing 2.25 by 0.95 mm. Length of male 2 mm, of female 2.8 mm.

*Immature stages.*—Larva 2.8 mm in length and 1.1 mm in diameter, white, with the caudal end of the last segment somewhat truncate but not blackened, the skin spines much reduced; each anterior spiracle with from 2 to 4 beads; posterior spiracles moderately separated, the slits short, broad, and semiovate, those of each spiracle arranged in a fan with the distal ends widely separated. Puparium 2.1 mm in length and 1 mm in diameter, straw colored to pale brown, the caudal end rounded, segmental sutures defined but inconspicuous.

*Hosts.*—The larvae feed in the flowers. Reared from the mistflower, *Eupatorium coelestinum* (*Conoclinium coelestinum*), from *Ageratum littorale*, and from a similar but unidentified composite with small lavender flowers.

*Distribution.*—The species was reared from the following Florida localities: Paradise Key, Opa Locka, 3 miles south of Florida City, 3 miles east of Wilson, 4 miles east of Wilson, Merritt Island, Broward County, Miami, Turners River, Lower Matecumbe Key, Key West, and Fort Christmas. Apparently generally distributed throughout the southern part of the State and abundant toward the tip of the peninsula. One specimen, presumably the same species, labeled Donna, Tex., was submitted by J. W. Monk as having been caught on *Grindelia*. Unique females are in the United States National Museum collection from Mexico and Nicaragua.

*Types.*—Holotype male, from 3 miles south of Florida City, reared from *Eupatorium coelestinum*, May 5, 1931; allotype female, same lot, May 6–7, 1931; 110 paratypes about equally divided as to sex, restricted to the series from the various Florida localities.

### XANTHACIURA TETRASPINA (Phillips)

(Fig. 33, *A–L*)

Described as *Aciura* (*Eucosmoptera*) *tetraspina* by Phillips (*69, p. 132*) in 1923.

*Adult.*—Similar to *X. insecta* (Loew) and differing therefrom by the following characters: Tending to be slightly smaller; thoracic venter black and concolorous with dorsum; abdomen yellowish with entire tip of dorsum black in both sexes, ovipositor sheath concolorously black; scutellum bearing a pair of short, but dark and distinct, apical bristles as well as the normal long, dark pair. Male forceps strongly incurved toward each other, the internal process with two distinct teeth. Wing marked in a similar manner to that of *insecta*, but all of the hyaline incisions along the posterior margin, with the exception of the two in the second posterior cell, coalescing along the margin with the hyaline axillary area, the third posterior cell thus relatively hyaline, except for an extension of black along distal portion of fifth vein and three additional, short, broad, black extensions along fifth vein below discal cell, the latter marked with either 2 or 3 hyaline droplets contiguous with the fifth vein, the proximal droplet sometimes present on one wing and absent on the other wing of the same individual; second vein relatively even throughout its course. Size: Male wing 2.6 by 0.9 mm, female wing 3 by 1.05 mm. Length of male 2.5 mm, of female 3.5 mm.

*Immature stages.*—Larva 3.7 mm in length and 1.6 mm in diameter, white, with the caudal end of the last segment somewhat truncate but not blackened; skin spines much reduced; each anterior spiracle with from 4 to 6 beads; posterior spiracles moderately separated, the slits short, broad, and semiovate, those on each spiracle arranged in a fan with the distal ends widely separated. Puparium about 3 mm in length and 1.8 mm in diameter, straw colored, the caudal end not conspicuously truncate; segmental sutures visible but inconspicuous.

*Hosts.*—The larvae feed in the flowers. Reared from the mistflower, *Eupatorium coelestinum* and from *Ageratum houstonianum.*

*Distribution.*—The species was described from Missouri, and is in the National Museum collection from Indiana and Texas. In Florida it was found only at Orlando, being replaced farther south by *X. connexionis.*

## THE GENUS ACINIA ROBINEAU-DESVOIDY

*Adult.*—Head with vertex slightly broader than maximum width of eye; frons flattened or slightly concave, more or less produced near antennae; mouth with a slightly raised edge; tongue short; third antennal joint distally somewhat angulate but not definitely pointed; head bristles pale brown but strong, except as otherwise noted; three pairs of frontal bristles, occasionally four bristles on one side on freak specimens; a band of pale deciduous hairs on each side of front near each eye, with similar hairs near center of front (scalelike in *fucata*); two pairs of upper orbital bristles, the upper pair pale and scalelike; one pair of long ocellar bristles; inner verticals very long and strong, nearly parallel; outer verticals conspicuously shorter, divergent; occipitals pale and scalelike, relatively long, but inconspicuously defined from the longest of the scalelike postocular cilia; the latter more or less alternating between long, pale, scalelike hairs and shorter bristles (scalelike in *fucata*); cheek cilia long, pale, but hairlike (somewhat flattened in *fucata*); cheek bristle long and strong (not conspicuous in *fucata*). Thorax, in back of the head, with a conspicuous brown polished spot (black in *fucata*, as in *Neaspilota*); thoracic dorsum clothed with flattened pale hairs (definitely scalelike in *fucata*); the normal bristles brownish but strong; dorsocentrals well in front of line of anterior supraalars, and almost on the suture; scutellum bearing two pairs of long, strong, brownish bristles. Abdomen, exclusive of the ovipositor sheath, somewhat shorter than thorax, and weak in appearance; fourth segment in female about equal in length with fifth; clothed with flattened pale hairs (definitely scalelike in *fucata*); ovipositor sheath broad, and as long as two preceding segments, or slightly longer. Male genitalia with the forceps curved toward each other, bent and at least in part with a somewhat concave surface (conspicuously so in *fucata*); internal process with two strong teeth (weaker in *fucata*). Wing with a reticulate pattern of fuscous brown, with luteous droplets, and hyaline spottings, presenting a more or less tricolored appearance (conspicuously so in *fucata*) which in addition to luteous droplets

has part of the central design of the wing luteous bordered by fuscous); first and third veins spined; anterior cross vein at about beginning of distal third of discal cell; the latter rather long; anal cell produced to a short point on sixth vein.

Type of the genus, *Acinia jaceae* Robineau-Desvoidy.

The generic name *Acinia* was proposed by Robineau-Desvoidy (*70, pp. 775–778*) in 1830 for seven specific names, including *jaceae* and *claripennis* described as new species. There was no designation or indication of the genotype. Walker (*90, pp. 75–79*), in 1836, discussed the genus, placing therein several of the specific names originally assigned to the genus by Robineau-Desvoidy, as well as other specific names, including *Acinia jaceae* Robineau-Desvoidy as a synonym of *Tephritis corniculata* Fallén and *Acinia claripennis* as a synonym of *Musca leontodontis* DeGeer. Westwood (*96, p. 148*), in 1840 under *Tephritis* Latreille, stated "See Mr. Walker's monograph, in the Entomol. Mag. vol. iii", and thereafter mentioned "*Acinia* Macq." as a subgenus of *Tephritis*, with *T. leontodontis* (sans authorship) stated as "typical species". The citation of typical species by Westwood has been accepted as genotype fixation by the International Commission on Zoological Nomenclature with a proviso that the "species was available as genotype". It might be argued that the citation by Walker of the originally included name *claripennis*, as a synonym of *leontodontis*, explained Westwood's concept of the latter and his reason for selecting it as the genotype. But the facts remain that Westwood did not cite one of the included names, that he did not state whether he accepted or rejected the Walker synonymy, and that he credited the generic name as subgeneric to Macquart. The author does not believe that rigidly construed Westwood fixed the genotype of *Acinia* Robineau-Desvoidy. Rondani (*74, p. 3*), in 1871, emended the name *Acinia* to *Acynia*, credited the name to Robineau-Desvoidy, and cited "*Tephritis corniculata* Zett." as genotype. This is a name not originally included by Robineau-Desvoidy in *Acinia*, but Rondani cited as a synonym the name *jaceae* Robineau-Desvoidy.

The generic name *Acinia* was used by a number of the earlier authors for North American species, especially for the group containing *bella* Loew and for which Loew erected the "subgenus" *Euaresta*. This usage is not in accord with any of the originally included species. *Acinia* was also used by early workers in the sense of *Eurosta;* but this is also contrary to the originally included species.

Hendel (*37, p. 136*), in 1927, resurrected the name *Acinia* to include two European species, *biflexa* Loew and *corniculata* Zetterstedt, citing the latter as the genotype and placing *jaceae* Robineau-Desvoidy in the synonymy. This is entirely in accord with the designation by Rondani.

The genus, as here used, equals *Oxyphora* of Loew (*59, p. 79*) in part. There is a decided possibility that some of the closely related European genera, now generally accepted as distinct, will ultimately have to be combined. There is also the possibility that the American *fucata* may eventually need a separate genus, based in part upon the characters indicated in the generic description. These characters, however, are only differences in degree, rather than sharp divergence.

The known larvae of both European and American species are feeders in the flowers of composites.

### ACINIA FUCATA (Fabricius)

(Fig. 34, *A–M*)

Fabricius (*26, p. 359*), in 1794, described a species stated to be from "*Americae meridionalis Insulis*", under the name *Musca fucata*, and in 1805 (*27, p. 321*) amplified the description. Wiedemann (*97, p. 505*), in 1830, is supposed to have compared specimens with the type, and Loew (*60, p. 302*), in 1873, accepted a Wiedemann specimen labeled "Buenos Ayres" and marked "type" as typical. Johnson (*44, p. 280*), in 1894, and Williston (*98, p. 377*), in 1896, record specimens from the West Indies; and the species has since been treated by many authors as occurring in the United States; see Doane (*25, p. 189*), Johnson (*48, p. 100; 49, p. 162*), Snow (*82, p. 345*), Aldrich (*2, p. 611*), Johnson (*52, p. 84*), Hendel (*36, p. 67*), and Phillips (*69, p. 150*).

Hendel sunk *Urophora tessariae* Kieffer (*55, p. 439*) as a synonym, but presumably incorrectly. The Kieffer species is stated to be a gall former on the stems of *Tessaria absinthoides*, and the Kieffer figure seems to represent a species quite distinct from the Florida series.

Insufficient West Indian and South American material prevents the author from changing the synonymy adopted by recent authors, but the Fabrician descriptions do not seem to fit, and in all probability will ultimately be found applicable to some other species, leaving the name *picturata* Snow, described as *Tephritis picturata* (*83, p. 173*) in 1894, for the North American species.

The species *fucata* has usually been placed in *Tephritis* or *Euribia* and not heretofore in *Acinia*.

Cole (*11, p. 473*), in 1923, described as a new species *Baryplegma maculipennis*, from a unique female type taken on Ceralbo Island, Gulf of California. No essential differences have been observed between Cole's figure and the Florida series, but the synonymy should await further specimens from Lower California.

*Adult.*—Head, including antennae, luteous, tinted with luteous brown, somewhat paler surrounding mouth and eyes, occiput with two black spots hidden by pollinose, and only visible on greasy specimens. Thorax with ground color bright yellow, dorsum marked with black, almost as in *Neaspilota*, and similarly marked with fuscous brown or blackish near and between the yellow legs and on metathorax; dark markings completely hidden by pollinose golden yellow and only visible on old or greasy specimens; scutellum yellowish, paler apically, and covered with the same pollinose as the remainder of the thorax. Abdomen with the ground concolorous with that of the thorax, tending to be slightly tinged with rufous, especially on old specimens, the ovipositor sheath with somewhat more of rufous cast and marked with blackish at tip. Size: Male and female wings about the same size, 3.4 to 3.5 mm by 1.4 mm. Length of male about 3.4 mm, of female 3.75 mm to 4 mm. Many runty specimens, males and females, are the result of improper or dried food. These have not been considered in the foregoing measurements.

*Immature stages.*—Larva white, soft, easily distorted, at least dorsally excurved, almost bean-shaped, measuring about 2.5 to 2.8 mm in length and 1.3 to 1.4 mm in diameter; segments very prominent, last segment with conspicuous folds and wrinkles caudally which surround the posterior spiracular area and never appear quite the same on any two larvae; skin densely covered with minute spines, although appearing smooth; anterior spiracles so reduced in size that they are difficult to see, each with 2 beads, possibly 3 in some specimens; posterior spiracles not widely separated, yet appearing so owing to their reduced size, the slits short, narrow, parallel sided, those on each spiracle practically contiguous mesially and arranged in a fan. Puparium bean-shaped, glossy rufous brown dorsally and laterally, somewhat paler and gray on the ventral surface, about 2 to 2.4 mm in length and 1.1 to 1.4 mm in diameter.

*Hosts.*—The larvae feed in the flowers of *Pluchea*, and were reared from *P. foetida*, *P. purpurascens*, *P. imbricata*, and an unidentified composite, probably a *Pluchea*.

*Distribution.*—The species appears to be generally distributed and not rare in Florida, recorded from as far north as Jacksonville and as far south as Key West. Also recorded from New Jersey, Florida (types of *picturata*), the West Indies (type of *fucata*), the Islands of Jamaica and St. Vincent, and Argentina; but at least some of the records are probably based on more than a single species.

## THE GENUS EUARESTA LOEW

*Adult.*—Head with vertex broader than maximum width of eye; frons tapered, only slightly produced near antennae; third antennal joint lobate; 2 pairs of yellowish brown frontal bristles, with 2 irregular bands of small, pale hairs and scalelike hairs, 1 band on each side of front near each eye; 2 pairs of upper orbitals, the lower pair strong and yellowish brown, the upper pair weaker and matching the occipitals in color and texture; 1 pair of long, strong, yellowish brown ocellar bristles; occipitals parallel, or nearly so, not conspicuously defined by color, texture, or length from the postocular cilia; inner verticals long, strong, and yellowish brown; outer verticals similar in color and texture to the postocular cilia, but somewhat longer; postocular cilia pale and scalelike, but relatively strong; cheek bristle somewhat darker than the cheek cilia but inconspicuous. Thoracic dorsum clothed with deciduous, pale, scalelike hairs, all of the bristles yellowish brown; dorsocentrals near suture and in front of line of anterior supraalars; scutellum with two pairs of long bristles. Abdomen, exclusive of the ovipositor sheath, approximately equal in length to thorax, ovipositor sheath basally as broad as preceding segment, tapering distally. Male genitalia with forceps reduced in length and pointed toward each other, the internal process short, stout, bearing two short, black teeth, and hidden by the main part of the much enlarged second genital segment, which distally bears several oblique ridges each side of anal region. Wing with a dark design interrupted by hyaline marginal indentations and hyaline spottings and droplets on the disk; first vein strongly spined; knob at junction of second and third veins with 2 or 3 small spines; typically the third vein with 2 or 3 deciduous spines, which are difficult to see, well before the anterior cross vein, and several similar spines distad of cross vein; first posterior cell with a black callus distorting the wing membrane close to the third vein; anterior cross vein more or less distad of basal two thirds of discal cell; the latter long and relatively close to the wing margin; anal cell inconspicuously pointed on sixth vein.

Type of the genus, *Trypeta festiva* Loew.

The generic name *Euaresta* was proposed by Loew (*60, p. 295*), in 1873, for a subgenus of *Trypeta*. Williston (*98, p. 377*), in 1896, used the spelling *Evaresta*. From about 1900 the name *Euaresta* has been used in the generic sense to include a large number of species, the different authors limiting or defining the genus in a somewhat different manner. Coquillett (*14, p. 540*), in 1910, designated the genotype as *festiva* Loew, and since that date authors have consistently retained the Coquillett type fixation but have not agreed regarding what other species to consider congeneric. In the main, authors have assigned to the genus most of the smaller American species having the scutellum 4-bristled and the wing more or less reticulated, but have generally assigned *Trypeta mexicana* Wiedemann to the genus notwithstanding the fact that this species has a scutellum bearing only 2 bristles, as well as usually eliminating from the genus *Trypeta abstersa* Loew, which has a 4-bristled scutellum. In short, from this standpoint the genus would be scarcely if at all distinct from *Trupanea*.

There exist a number of closely related species which agree more or less in the chaetotaxy of the head and thorax; possess at least a few

spines on the third vein; and further agree by having the second male genital segment greatly specialized, being so enlarged that it cannot be retracted, and also conspicuously striated with oblique ridges and depressions. This group of species includes, among others, *aequalis* Loew, *festiva* Loew, *bella* Loew, *bellula* Snow, *stelligera* Coquillett, *tapetis* Coquillett, and *bullans* Wiedemann, but does not include *mexicana* Wiedemann, *abstersa* Loew, *pura* Loew, or *subpura* Johnson, or any of the species usually assigned to *Trupanea*.

Hendel (*38, p. 368*), in 1928, split the genus *Euaresta* into several divisions which he called genera, and to *Euaresta* in the restricted sense assigned *festiva*, *bella*, and *bellula*, defining the genus as possessing 4 bristles on the scutellum, 2 pairs of frontal bristles, and 1 to 3 spines on the third vein, evidently having overlooked some of the spines. These three species further agree by having a distinct black callus in the first posterior cell. In 1914 (*35, p. 95*) Hendel proposed the name *Camaromyia* in a key, with *Trypeta bullans* Wiedemann, sole species and designated type, later in the same year (*36, p. 63*) again publishing the same generic name as "new", keeping the same genotype but, in addition, placing under the generic name the North American *aequalis*.[7] The genus was largely based on the characters of two pairs of frontal bristles, a conical-shaped ovipositor sheath, and a naked third vein. Actually, in the genotype, there are a couple of small and deciduous bristles on the knob at the junction of the second and third veins, and by examining a long series of specimens a single similar bristle was located on 1 specimen, on that part of the third vein over the first basal cell, while several specimens showed 1 or 2 such bristles beyond the anterior cross vein. The presence of these few bristles in *Camaromyia*, together with the similar chaetotaxy of head and thorax and the peculiarly specialized male genitalia, indicates the close affinity between this group and *Euaresta* (in the restricted sense). The presence of the black callus in the first posterior cell of *Euaresta* and its absence in *Camaromyia* will distinguish the two groups. Whether this latter character is of generic or of subgeneric significance must await biological and revisional studies.

#### EUARESTA (EUARESTA) BELLA (Loew)

(Fig. 35, *A–G*)

Described as *Trypeta bella* by Loew (*57, p. 88*) in 1862, an adoption of an undescribed Fitch name. The species has been discussed by a number of authors.

*Adult.*—Head, including the antennae, yellowish. Thorax with the ground color blackish, with some luteous which tints the area above the fore coxa, the humerus, the lateral sutural area to the wing base, and most of the scutellum, the entire thorax heavily pollinose with golden yellow. Legs yellow. Abdomen luteous, often with more or less of a rufous tinge especially in old or greasy specimens, pollinose, clothed with sparse yellow hairs and scalelike hairs; ovipositor sheath dark brownish rufous, almost fuscous, tending to be cylindrical although frequently flattened, sparsely clothed with fine yellowish hairs, and of a length nearly equal to that of the three preceding segments. Wing with an inconspicuous

[7] *Setigeresta* new subgenus. Type, *Trypeta aequalis* Loew. Monobasic. Differs from all genera and subgenera of the *Euaresta* group by having the knob at the junction of the second and third veins, and the third vein definitely bristly. Also differs from *Euaresta* by lacking the callus in the first posterior cell, and from *Camaromyia* by the more lobate antenna. Otherwise the characters are as given under *Euaresta*. The larvae feed in the seed pods of cocklebur, *Xanthium* (*62, 63, and 64*). The biology of *Euaresta* is unknown, but is presumably quite different. The species was not collected in Florida, but adult specimens taken in Alabama just over the Florida line were submitted for identification.

hyaline basal area, but otherwise mostly covered by a dark design ranging in color from luteous brown to fuscous brown which is interrupted by hyaline forming indentations along the wing margins and droplets in the cells. Size (based on Florida material): Variable, the smallest male with a wing measuring 2.2 by 0.9 mm and a length of 2.4 mm, and the largest having a wing 2.9 by 1.15 mm, larger than that of the largest female; average female length 3 mm.

Florida specimens seem to average smaller than those from farther north but no constant differences in either structure or coloration could be found.

*Immature stages.*—Unknown.

*Hosts.*—Unknown.

*Distribution.*—Recorded as abundant and generally distributed from New England to Florida and west to Colorado and Texas; also recorded from Mexico and the Bahama Islands. Specimens are usually caught on ragweed, *Ambrosia artemisiaefolia.* Adults were quite numerous at Orlando, Fla., on this plant, and occasionally on other weeds growing within a few inches of ragweed. Repeated searching of ragweed did not reveal the biology of the insect.

## THE GENUS DYSEUARESTA HENDEL

*Adult.*—The description of *Euaresta* applies with the following exceptions: Third antennal joint not lobate; the pale deciduous scale-like hairs which replace bristles similar in both genera; but the yellowish brown bristles of *Euaresta* black or dark brown in *Dyseuaresta;* a pair of short, but distinct, deciduous, yellowish, scalelike hairs below the 2 pairs of frontal bristles (indicating the reduced lower pair of frontal bristles of *Trupanea);* cheek bristle darker than the cheek cilia, all longer than in *Euaresta;* scutellum with only 1 pair of very long bristles, the posterior pair absent or possibly replaced by 2 small, deciduous, pale, scalelike hairs usually lost by rubbing; main part of second genital segment large, but lacking distal ridges; forceps reduced in length, but bent and semiparallel to each other; internal process short and stout, bearing 2 black teeth exposed by the bending of the forceps. Wing with knot at junction of second and third veins with 2 or 3 small spines; third vein with at least 1 small deciduous spine near knot, and with about 4 similar spines on the part of the third vein over the first posterior cell; an evanescent callus in first posterior cell, visible on dark specimens, obsolescent on specimens which are not fully colored.

Type of the genus, *Euaresta adelphica* Hendel.

The generic name *Dyseuaresta* was proposed by Hendel (*38, p. 368*), in 1928, for *Euaresta adelphica* Hendel, *Euaresta gephyrae* Hendel, and *Trypeta mexicana* Wiedemann with *adelphica* designated as type. The original description cited characters of a 2-bristled scutellum, 2 pairs of frontal bristles, an unspined third vein, and a normal black abdomen. *Euaresta adelphica* is unknown to the author, except from the literature. Hendel's figure (*36, fig. 64*) represents a wing which appears almost identical with that of *mexicana,* and shows the evanescent callus in the first posterior cell. There seems little doubt that *adelphica* is correctly associated with *mexicana.* The characters, in the generic description written by the author, have been taken from specimens of *mexicana* from Florida.

### DYSEUARESTA MEXICANA (Wiedemann)

(Fig. 36, *A-G*)

Described as *Trypeta mexicana* by Wiedemann (*97, p. 511*) in 1830. Loew, in 1862 (*57, pp. 59, 96*), stated that the species was unknown to him and described *Trypeta melanogastra* (*57, p. 90*), but in 1873 (*60, p. 319*) published a figure of the wing of the Wiedemann type and indicated the probable synonymy. Since that date several names have been proposed for other supposed species in the group, the names

usually based upon single specimens or very short series. The characters used to define these species have been the exact spotting on the wing, the presence or absence of certain hyaline spots, or the sizes, positions, and shapes of these spots. As will be noted from the following description based on reared specimens, these characters are subject to much variation. Nevertheless, in the very few tropical specimens which have been available, there exists sufficient difference in the proportionate length of the female ovipositor sheath to indicate the possibility of several very closely related tropical species. The author was unable to see any distinguishing characters between the Loew type of *melanogastra* and the Florida series, excepting that the type had the hyaline droplet, which is situated near the middle of the submarginal cell, below the dark bar which divides the two large hyaline patches in the marginal cell. Other specimens in the collections of the Museum of Comparative Zoology and of D. M. Bates indicate that this slight difference is of little or no significance. Among the other names proposed in the group is *Euaresta plesia* Curran (*20, p. 71*). The author was unable to find any characters to differentiate the type from the Florida series.

*Adult.*—Head, including the antennae, yellowish. Thorax black, tinged with some brown; humerus, wing base, and tip of the scutellum tinted with yellowish; most of thorax and abdomen clothed with sparse, yellow, deciduous, scalelike hairs. Legs yellow. Abdomen black or blackish brown, more or less basally tinted with yellow, the first segment, and sometimes the second, frequently appearing luteous. Ovipositor sheath black or blackish brown, nearly as long as the remainder of the abdomen. Wing with an inconspicuous hyaline basal area, otherwise mostly covered by a fuscous-brown design interrupted by hyaline forming indentations along the wing margins and droplets in the cells, the hyaline part of the wing variable, the number of spots in the discal cell ranging from 1, the usual number, to 4, the droplet in the second posterior cell frequently coalescing with the nearest marginal indentation, the hyaline in the third posterior cell near the sixth vein either more or less coalescing or irregularly divided into spots. Size: Variable, the smallest and largest specimens being females, the wing measuring from 2.4 by 1 mm to 3.25 by 1.25 mm, and the length from 3 to 4 mm.

The foregoing description is based entirely upon bred Florida specimens.

*Immature stages.*—Unknown.

*Host.*—*Melanthera* sp.

*Distribution.*—Specimens were obtained by caging the flowering heads of the host,[8] but comparatively few adults were obtained from hundreds of the flowers. Quantities of the host from Lower Matecumbe Key, from Williston, and from several localities in Brevard County were caged, and on each occasion this host yielded some adult flies. The species seems widely distributed, and not rare, in Florida. It has been recorded from Texas, Mexico, Cuba, Puerto Rico, St. Vincent, the Bahama Islands, and Paraguay. Some of the records may refer to distinct, but closely related, species.

## THE GENUS TRUPANEA GUETTARD

*Adult.*—Head with vertex subequal to maximum width of eye, frons tapered and produced; third antennal joint relatively broad, not conspicuously pointed; arista somewhat pubescent; head bristles black or blackish brown, except occipitals, outer verticals, superior pair of upper orbitals, postocular cilia, and the cheek bristle and cilia; typically with 3 pairs of frontal bristles, the lower pair much reduced in length; atypically with the lowest pair subequal with the other

[8] The host dries rapidly after being cut, and this may account, at least in part, for a considerable percentage of undersized specimens. The variation in size and in wing markings recorded in the above description of the adults was not restricted to any locality.

frontal bristles, or lacking the lowest pair of frontal bristles; typically the front with a band of irregularly arranged, short, thin, pale cilia near edge of each eye, and with the center naked; atypically with the cilia near the eyes mixed with scalelike hairs, and with scalelike hairs on or near center of frons; 2 pairs of upper orbital bristles, the dorsal pair pale and scalelike; 1 pair of ocellar bristles; inner verticals long; outer verticals and occipitals pale and scalelike, inconspicuously longer than postocular cilia. Thoracic dorsum clothed with scalelike hairs, with the dorsocentral bristles cephalad of the anterior supraalars and close to the suture; scutellum with at least some scalelike hairs, easily rubbed off, typically with 1 pair of bristles, atypically with 2 pairs. Abdomen, exclusive of the ovipositor sheath, approximately equal in length to the thorax; ovipositor sheath typically quite long and broad, about equal in length to the 3 preceding segments; atypically, broad but short, being shorter than the 2 preceding segments. Male forceps narrower than dorsal part of second genital segment, and incurved toward each other; internal process with two strong teeth. Wing typically with a subapical dark stellate pattern, the dark rays running toward the wing margins, the basal part of the wing hyaline; atypically, with the basal part of the wing having reticulate markings, and the ray to the stigma often very broad; first vein strongly bristled; third vein naked; anterior cross vein distad of basal two thirds of discal cell; anal cell inconspicuously produced to a short point.

Type of the genus, *Trupanea radiata* Fabricius (presumably a synonym of *Musca stellata* Fuessly).

The generic name *Trupanea* was first proposed by Guettard (*31, pp. 171–173*) in a work which, though listed as of 1756, appears to have been printed as a unit in 1762. The work is binary but not binomial, the species being described but not named. Schrank (*76, p. 147*) in 1795 or 1796 adopted and used the Guettard generic name with *radiata* as sole included species. The generic name was again used in 1803 by Schrank (*77, pp. 140–151*), who included under it all of his "*Bohrfliege.*" The name has since been used by many authors, although emended by Bezzi (*5, pp. 84, 166*) in 1913 to *Trypanea*, a spelling subsequently adopted by both Hendel and Phillips. The name *Trupanea* has usually been credited to Schrank as of 1803, but several recent papers have cited the Schrank 1795–96 reference. The generic name *Urellia* Robineau-Desvoidy (*70, p. 774*)—proposed in 1830 to accommodate two new specific names, *calcitrape* and *parisiensis*, both of which appear to be synonyms of *stellata*—falls as a synonym of *Trupanea*. The name *Urellia* was used extensively by authors before 1910, and most of the species described under this name belong in *Trupanea*.

The groups treated as subgenera of *Trupanea* in the present paper are of equivalent taxonomic value with many groups normally considered generic in the family. The author is not inclined to place generic valuation upon such characters as the presence or absence of basal maculation on the wing, the presence or absence of the lowest pair of frontal bristles, and the presence or absence of the apical pair of bristles on the scutellum. These characters have been consistently used in the past to separate genera or groups of genera. *Actinoptera* Rondani, *Ditricha* Rondani, and *Euarestella* Hendel, used as genera by Hendel (*37*) in 1927, are probably of subgeneric significance. The subgenus *Goniurellia* Hendel (*37, pp. 23, 198*) is probably available for some of the species of *Trupanea* from the Western States. *Trupanea*, in the sense herein employed, includes *Euribia* of authors and of Hendel 1914 (*35, 36*) but not 1927 (*37, p. 37*), *Tephritis* of authors and of Hendel 1927 (*37, p. 176*), at least in part, and *Euaresta* of American authors, in part.

## THE SUBGENUS TRUPANEA GUETTARD

This is the typical subgenus of the genus *Trupanea* and has been described under the generic heading. The term "atypical" has been used in the generic description to point out those characters which are not possessed by the species of the typical subgenus. The stellate subapical pattern of the wing together with the lack of basal wing markings; the 2-bristled scutellum; the possession of 3 pair of frontal bristles, the lowest pair somewhat reduced; and the rather long ovipositor sheath, serve to differentiate this subgenus from the others under consideration.

The known larvae are typically feeders in flowers, or bore into the tender terminal stems.

### TRUPANEA (TRUPANEA) DACETOPTERA Phillips

(Fig. 38, *A–G*)

Described as *Trypanea dacetoptera* by Phillips (*69, p. 148*) in 1923. The type of *Trypeta* (*Urellia*) *polyclona* Loew (*60, p. 324*), in the Museum of Comparative Zoology, seems closely related, and the Loew name may ultimately have to replace *dacetoptera*. Slight differences, probably of specific significance, seem to exist in the maculation of the wings. No trace of any apical pair of bristles was found on the scutellum of the Loew type. Further Cuban material will be necessary to settle the status of the name *polyclona*.

*Adult.*—Head, including antennae, yellowish brown; front suffused with pale pollinose gray which obscures the ground color and forms a stripe along the side of each eye. Thorax, including the scutellum, with a fuscous ground color marked by clay yellow near the spiracles, on the humeri, and on the sutures; pollinose, fresh specimens appearing bright gray, greasy or old specimens appearing dull black with the yellowish markings relatively conspicuous. Legs clay yellow. Abdomen concolorous with the thorax and pollinose in a similar manner. Wing entirely hyaline basally, distally with a brownish-fuscous stellate design sending five rays to the posterior margin and a short ray into the discal cell, the rays somewhat variable in width and shape as between different individual specimens; first basal cell with an apical fuscous-brown suffusion, occasionally a trace of a detached fuscous mark on or below the fifth vein. Male genitalia with the forceps curved toward each other, the inner process relatively strong and bearing two claws. Ovipositor sheath approximately as long as the three preceding segments. Size: Male wing 3 to 3.3 mm by 1.1 to 1.35 mm, female wing 3 to 3.5 mm by 1.25 to 1.4 mm. Length of male 3.2 to 3.3 mm, of female 3.6 to 3.8 mm.

*Immature stages.*—Unknown.

*Hosts.*—The food plants are *Gnaphalium obtusifolium* and *Chrysopsis microcephala*. The larvae are scarce and very difficult to find. Several adults were obtained by placing large quantities of *Gnaphalium* in breeding cages. On one occasion a few larvae and puparia were found in the tender tips of nonflowering plants of *C. microcephala*, and two adults were obtained from these.

*Distribution.*—Apparently rare and local in Florida, the only definite records being from Orlando. Previously recorded from New York (the types) and from New England. The species was unrepresented in the collections of the United States National Museum.

### TRUPANEA (TRUPANEA) MEVARNA (Walker)

(Fig. 39, *A–L*)

Described as *Trypeta* (*Urellia*) *mevarna* by Walker (*91, p. 1023*) in 1849. A photograph of the wing of the alleged type which is in the British Museum shows a wing identical with that of a specimen

compared with, and agreeing with, the type of *solaris* Loew. Walker stated that the type had 9 dark rays and 2 included hyaline drops, indicating either a specimen of *dacetoptera* or an erroneous description. In this regard Loew (*60, p. 325*) seemed dubious of the validity of *polyclona*, but never questioned the distinctness of *solaris*. However, the British Museum specimen is considered by the author as probably the type, pending contrary evidence. This makes the Loew species, described as *Trypeta solaris* (*57, p. 84, pl. 2, fig. 19*) in 1862, a synonym. The Loew figure does not fit his description in details of maculation, but the specimen labeled type in the Museum of Comparative Zoology closely agrees with both the original description and the amplified description by Loew (*60, p. 325*) in 1873.

Several recent authors, Hendel (*36, p. 76*), Phillips (*69, p. 148*) and Curran (*22, p. 6*), have sunk the name to *daphne* Wiedemann (*97, p. 508*), with *duplicata* Wiedemann (*97, p. 510*) placed in the synonymy by Hendel, followed by Phillips. The Wiedemann species were described from Montevideo, Uruguay. None of the South American specimens which have been studied seem identical with any of the Florida series. The group contains a number of very closely related species which seem individually variable on many of the characters formerly considered of specific significance; especially in the presence or the absence of an isolated blackish mark on the fifth vein, and whether or not the first blackish ray in the discal cell touches the fifth vein. These characters seem, in part, sexual, although often not definitely so.

Coquillett (*13, p. 266*), in 1899, sunk *solaris* Loew and *actinobola* Loew to *mevarna* Walker. Many of the subsequent authors have used the name *mevarna* in place of *solaris*, but have retained the name *actinobola* in the category of an unidentified name.

Apparently *mevarna* is a relatively rare species in collections, and the names *daphne*, *mevarna*, and *solaris* as used by most North American authors usually refer to smaller species more closely related to *actinobola*.

The Florida series, described below, closely agrees with the Loew type of *solaris*.

*Adult.*—Entirely similar to *dacetoptera*, except as follows: Fifth posterior ray, counting from wing apex, ending at fifth vein instead of attaining wing margin; sixth ray much shorter and only indicated by a slight shading in the discal cell near the anterior cross vein; brownish suffusion in first basal cell frequently intensified, sometimes with a blackish blotch in the center of the brownish suffusion; ovipositor sheath about equal in length with that of the four preceding segments. Size: Male wing 3.4 to 3.6 mm by 1.4 to 1.5 mm, female wing 3.7 to 4 mm by 1.5 to 1.65 mm. Length of male 3.5 to 3.8 mm, of female 4 to 4.15 mm.

*Immature stages.*—Larva white; about 3.6 to 3.9 mm in length by 1.5 to 1.7 mm in diameter; skin stippled with minute spines scarcely noticeable toward the caudal parts of most of the segments; each anterior spiracle with about 5 to 7 beads; posterior spiracles like those of *Neaspilota*. Puparium black, about 3.5 mm in length and 1.5 to 1.6 mm in diameter.

*Hosts.*—The larvae feed in the flowers, buds, and tender tops of plants of the genus *Chrysopsis*. Adults were reared from *C. graminifolia*, *C. latifolia*, *C. oligantha*, and *Chrysopsis* sp.; also reared from flowers of a plant identified questionably as *Chrysopsis microcephala*.

*Distribution.*—The Florida series was reared from several scattered localities and indicates that the species is generally distributed throughout the northern half of the State, but local, and not abundant.

The Loew type came from Georgia, the Walker type from Florida. Recorded by various authors, under various names, from New England west to Colorado, Nebraska, and Oregon, and southward to Florida, Texas, and California; also from Mexico, the West Indies, and several countries in South America. Most of the records are apparently based on incorrect identifications or on erroneous synonymy.

#### TRUPANEA (TRUPANEA) AGERATAE, new species

(Fig. 40)

*Adult.*—Entirely similar to *dacetoptera*, except as follows: With more of a tendency for the hyaline incisions between the dark rays to be broken into drops; fifth posterior ray, counting from wing apex, ending at fifth vein but in so doing broadened to define two hyaline drops; sixth posterior ray with a slightly disjoined, large, black patch on the fifth vein which helps form the outline of a hyaline drop in the discal cell below the anterior cross vein; the brown in the first basal cell as dark as in the darkest specimens of *dacetoptera*. Agrees with *mevarna* in the length, but not in the direction, of the fifth ray, but disagrees in the sixth ray and the strong detached spot on the fifth vein, as well as disagreeing by the general droplike nature of the hyaline on the distal part of the wing. Size: Male wing 2.5 by 1.05 mm. Length of male 2.6 mm.

*Immature stages.*—Undescribed.

*Host.*—The larvae feed in the flowers of *Ageratum littorale*.

*Distribution.*—No Name Key, Fla., only definitely known locality.

*Type.*—Holotype male, November 23, 1930, unique.

*Notes.*—Larvae and puparia of a *Trupanea*, probably the same species, were also noticed in *Ageratum littorale* at Key West by Nicholson, but the material was not reared.

#### TRUPANEA (TRUPANEA) ACTINOBOLA (Loew)

(Fig. 41, *A–K*)

Described as *Trypeta* (*Urellia*) *actinobola* by Loew (*60, p. 326*) in 1873. The specimens labeled types in the Museum of Comparative Zoology represent two forms or species, the one agreeing with the original description, the other having the second costal hyaline V crossing the second longitudinal vein and reaching half across the submarginal cell. None of the Florida specimens appear to perfectly match either of the two types, and very probably none is conspecific, yet the one Loew type which does agree with the original description differs so little from the Florida series that the introduction of a different specific name seems superfluous until some of the various Texas forms are reared to ascertain the variation within specific units. Most of the specimens labeled *daphne*, *mevarna*, and *solaris* in collections from North America belong in the *actinobola* complex. Several forms from the Southwest have received names, but these must await rearing before the synonymy can be established.

*Adult.*—Very similar to *dacetoptera* and to *mevarna*, but smaller. Agrees with the latter in that the fifth posterior dark ray ends on the fifth vein and does not attain the wing margin. Disagrees with both species in the generally neater pattern and narrow rays; in almost lacking any trace of a sixth posterior ray; in that the first basal cell lacks brown tinting, except usually for some fuscous brown or blackish along the anterior cross vein, this coloration obsolete individually. A detached, dark mark individually present or absent on the fifth vein almost in a transverse line with the termination of the first vein; in the present species, apparently not a secondary sexual character. Slight differences, possibly of little significance, seem to exist in the male genitalia. Ovipositor sheath scarcely, if at all, longer than the two preceding abdominal segments. Size:

Male wing 2.1 to 2.5 mm by 0.95 to 1.05 mm, female wing 2.6 to 2.85 mm by 1 to 1.1 mm. Length of male 2.1 to 2.6 mm, of female 2.5 to 3 mm.

*Immature stages.*—Undescribed except for the puparium, which is similar to that of *mevarna* but smaller, measuring 2 to 2.1 mm in length and 1 to 1.25 mm in diameter. The puparium shows the larval skin to possess minute spines as in *mevarna*, the posterior spiracles similar to those of that species, the anterior spiracles with about four beads.

*Hosts.*—The larvae feed in the flowers of various composite plants, only very rarely more than a single larva in any one flower. None were found feeding in the buds, or in the tender tips of nonflowering plants. Adults were reared from *Erigeron vernus*, *E. quercifolius*, and various species of *Solidago;* also from 1 to 3 adults were obtained from each of the following hosts: *Aster adnatus*, *A. carolinianus*, *Actinospermum angustifolium*, *Coreopsis* sp., and *Hieracium* sp.

*Distribution.*—The Loew types are stated to have come from Texas (Belfrage). The Florida series came from various localities throughout that State, indicating a generalized distribution, seldom abundant, yet never rare. Specimens agreeing perfectly with the Florida series are in the collections of the United States National Museum, and are labeled as having been reared from *Erigeron vernus* at Brownsville, Tex., by J. C. Bridwell. Other specimens, which seem probably conspecific, indicate a generalized distribution throughout at least the eastern part of the United States.

#### TRUPANEA (TRUPANEA) ECLIPTA, new species

(Fig. 42, *A–K*)

*Adult.*—Closely related to the Florida series described under the name *actinobola*, and intermediate in average size between that species and *mevarna*. Differing from the former by the oblique dark band from the stigma toward the anterior cross vein being incomplete, and in that the second hyaline costal area, counting from the stigma, crosses the second vein and forms a large, often semidetached, drop in the submarginal cell, a character probably subject to more variation than that shown by the type series. Apparently lacking all traces of a detached dark mark on the fifth vein. Male genitalia very similar to those of *actinobola*. Ovipositor sheath of approximately the same width as that of *actinobola* but conspicuously longer, being approximately equal in length to that of the three preceding abdominal segments. Size: Male wing 2.8 to 3.05 mm by 1 to 1.2 mm, female wing 2.8 to 3.4 mm by 1.15 to 1.4 mm. Length of male 2.8 to 3 mm, of female 3.3 to 3.6 mm.

*Immature stages.*—Undescribed except for the puparium, which is similar to that of *mevarna*, but smaller, measuring 2.4 to 2.8 mm in length and 1.3 to 1.4 mm in diameter. The puparium showing the larval skin with minute spines as in *mevarna*, the posterior spiracles similar to those of that species, the anterior spiracles with about five beads.

*Host.*—The larvae feed in the flowers of *Eclipta alba*.

*Distribution.*—Only known locality, Orlando, Fla.

*Types.*—Holotype male, November 1, 1930; allotype female, same date; 170 paratypes, about equally divided as to sex, various dates from August 16 to November 2, all 1930.

### THE SUBGENUS EUARESTOIDES, NEW SUBGENUS

Type of the subgenus, *Trypeta abstersa* Loew.

The subgenus *Euarestoides* differs from the typical subgenus by having the stellate subapical mark inconspicuous because of a general reticulate pattern which more or less covers the entire wing; by three pairs of subequal frontal bristles; by the irregular band of pale hairs on each side of the front near the eyes, composed of mixed pale hairs and deciduous pale scalelike hairs, and with additional pale scalelike hairs near the center of the frons; by the scutellum with two

pairs of strong bristles; by the relatively short ovipositor sheath; and by a stronger clothing of scalelike hairs on the thorax and abdomen.

In Hendel's tables (*37, pp. 16–23*) the present subgenus falls between *Acanthiophilus* and *Tephritis*, fitting neither. The genus *Camaromyia*, which Hendel includes in the same group of genera, has been treated (p. 50) as a subgenus of *Euaresta*.

In *Euarestoides* the author places *abstersa* Loew and *acutangula* Thomson, distinct species, which have usually been considered synonymous, and which have repeatedly been shifted from one genus to another. The known larvae are feeders in flowers.

#### TRUPANEA (EUARESTOIDES) ABSTERSA (Loew)

(Fig. 43, *A–L*)

Described as *Trypeta abstersa* by Loew (*58, p. 221, no. 77*), in 1862. The species has since been repeatedly shifted from one genus to another. Loew (*60, p. 323*), in 1873, and Osten-Sacken (*66, p. 194*), in 1878, placed the species in *Trypeta* (*Urellia*); Doane, 1899 (*25, p. 192*), in *Urellia;* Coquillett, 1899 (*13, p. 265*), in *Euaresta;* Johnson, 1900 (*45, p. 688*), and Van der Wulp, 1903 (*100, p. 426*), in *Urellia;* Johnson, 1903 (*47, p. 106*), in *Euaresta;* Snow, 1904 (*83, p. 345*), Adams, 1904 (*1, p. 450*), and Aldrich, 1905 (*2, p. 613*), in *Urellia;* Cresson, 1907 (*15, p. 106*), in *Euaresta;* Johnson, 1909 (*50, p. 113*), 1910 (*51, p. 803*), and 1913 (*52, p. 84*), in *Urellia*; Hendel, 1914 (*36, p. 81*), Phillips, 1923 (*69, p. 148*), Johnson, 1925 (*53, p. 264*), Johannsen, 1928 (*43, p. 853*), and Curran, 1932 (*22, p. 6*), in *Trypanea.* The closely related species *acutangula* Thomson was described in 1868 (*88, p. 583*) in *Trypeta*, and subsequently usually considered a synonym of *asbstersa*, but placed in *Trypeta* (*Tephritis*) by Loew (*60, pp. 335, 342*) in 1873, in *Trypeta* (? *Tephritis*) by Osten-Sacken (*66, p. 194*) in 1878, and in *Tephritis* by Aldrich (*2, p. 611*) in 1905.

*Adult.*—Head, including antennae, yellowish: metanotum dark brown; otherwise head, thorax, abdomen, and all appendages yellowish, excepting the wing, which is hyaline with a dark subapical stellate design and reticulate markings. Specimens which have been killed and preserved tend to have the thoracic dorsum and the dorsum of the abdomen darkly discolored by grease. Size: Male wing about 3.4 by 1.3 mm, female wing 3.5 by 1.4 mm. Length of male 3 mm, of female 3.4 mm.

*Immature stages.*—Larva white; short and stout, about 2.1 to 2.5 mm in length and 1.3 mm in diameter; the skin minutely spinulose, the spines tending to form irregular bands on the cephalic parts of the third to ninth segments, and on the dorsocaudal and caudolateral parts of the last two segments; anterior spiracle averaging five beads; each posterior spiracle with the slits parallel sided and relatively straight, arranged in a fan, the spiracular plate obsolescent, only slightly indicated below. Puparium scarcely smaller than the mature larva, blackish brown, the segmental sutures poorly defined.

*Host.*—The larvae feed in the flower heads of *Trilisa paniculata.*

*Distribution.*—The species was reared in quantity from localities in Orange County, Fla., where it was abundant. Recorded from New England to Florida and Texas, and westward to California, also from Cuba, Mexico, and South America, but at least two species are involved in these records.

### THE SUBGENUS TEPHRITOIDES, NEW SUBGENUS

Type of the subgenus, *Euaresta subpura* Johnson.

Differs from the typical subgenus by having, in addition to a well-defined stellate subapical mark, a general reticulate pattern which more or less covers the basal portion of the wing, and a broad oblique band from the costa through the

stigma to, and including, the anterior cross vein; by possessing only two pairs of frontal bristles; in having the irregular band of pale hairs on each side of the front near the eyes mostly of a deciduous scalelike nature and with additional scalelike hairs near the center of the frons; by the scutellum having typically two pairs of long, strong bristles;[9] by the relatively short ovipositor sheath; and by the strong clothing of scalelike hairs on the thorax and abdomen.

In Hendel's tables (*37, pp. 16–23*) the present subgenus runs to *Tephritis* of Hendel, which appears to be a complex of more than one evolutionary group.

*In Tephritoides* the author places *subpura* Johnson, *pura* Loew, *pacifica* Doane, and several other species usually placed in *Euaresta* by American authors.

### TRUPANEA (TEPHRITOIDES) SUBPURA (Johnson)

(Fig. 44, *A–M*)

Described as *Euaresta subpura* by Johnson (*50, p. 114*) in 1909 and also placed in *Euaresta* by Phillips (*69, p. 147*) in 1923.

*Adult.*—Entire insect yellowish except for the tip of the ovipositor sheath, which is darkened, and the wing, which is hyaline, with a dark subapical stellate design, a broad, dark, oblique band from the costa through the stigma and anterior cross vein, and a generally dark reticulate pattern. Size: Male wing about 3.8 by 1.6 mm, female wing 4.4 and 1.8 mm. Length of male 4.5 mm, of female 4.75 mm.

*Immature stages.*—Larva white; measuring up to 4.4 mm in length by 1.9 mm in diameter; with the skin minutely spinulose, the spines tending to form irregular bands on the cephalic parts of the third to the ninth segments and on the dorsocaudal and caudolateral parts of the last two segments; the anterior spiracle averaging six beads; each posterior spiracle with the slits parallel sided, long, individually straight or angulate, subparallel, the spiracular plate obsolescent on the surface but strongly indicated below. Puparium slightly smaller than the mature larva, blackish brown, the segmental sutures poorly defined.

*Host.*—The larvae feed in the tender growing stems of *Baccharis glomeruliflora*, tunneling out as much as an inch of stem and usually, but not always, forming slight swellings.

*Distribution.*—In Florida the species is not rare, but is local, and was found only by Mr. Nicholson, and in localities in Orange, Osceola, Volusia, and Brevard Counties. Previously only recorded from the type specimens, taken on sea burweed (*Xanthium echinatum*) at Wildwood and Angelsea, N.J.

*Notes.*—The author was unable to distinguish between the Florida specimens and the type series in the Museum of Comparative Zoology. One of the paratypes, through the courtesy of the latter institution, has been deposited in the United States National Museum. Whether or not *Xanthium echinatum* is also a host must, for a time, remain unknown.

[9] Possibly only a single pair in some species, as according to Bezzi and Tavares (*7, pp. 163–165*) their new species *Trupanea majuscula* is a gall former on the stems of its host plant and has a 2-bristled scutellum. This species, which is only known to the author from the original description and figure, has the wing pattern of *subpura* Johnson.

FIGURE 11.—*Toxotrypana curvicauda: A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, head of adult female (front view); *I*, same (side view); *J*, median area of wing of male; *K*, adult female; *L*, abdomen of adult male (side view); *M*, male genitalia (from anal end); *N*, same (side view); *O*, abdomen of adult female showing ovipositor sheath (side view); *P*, ovipositor; *Q*, armature on membrane of ovipositor.

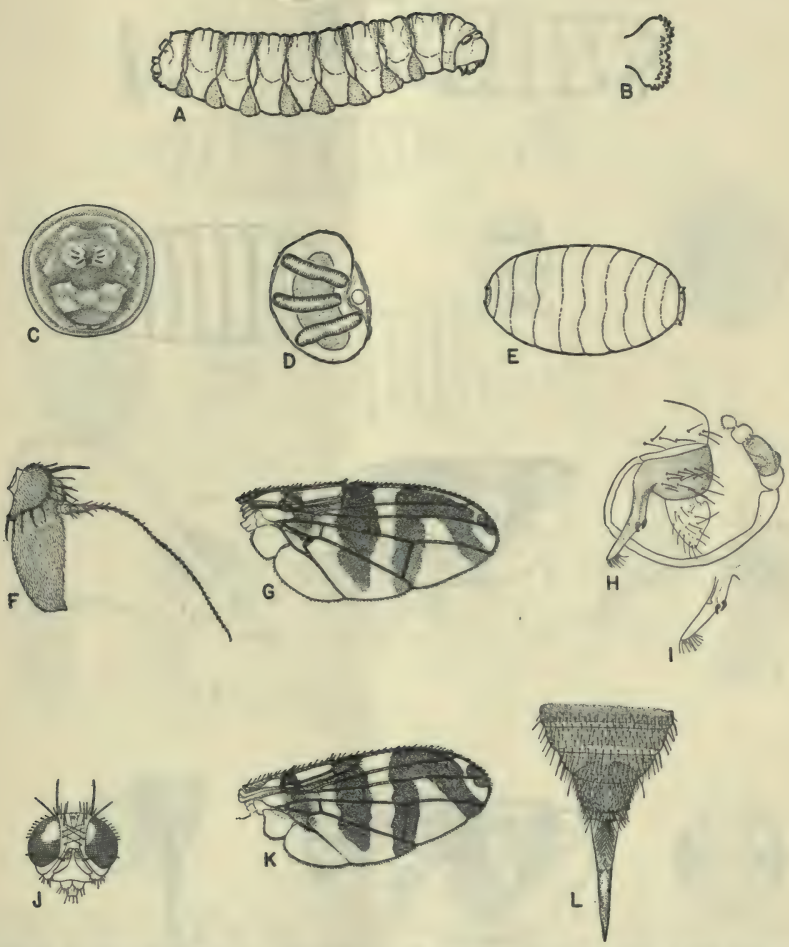


FIGURE 12.—*Rhagoletis cingulata:* *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (side view); *I*, inner surface of right half of forceps of male genitalia (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L* part of abdomen of adult female showing ovipositor (upper aspect)

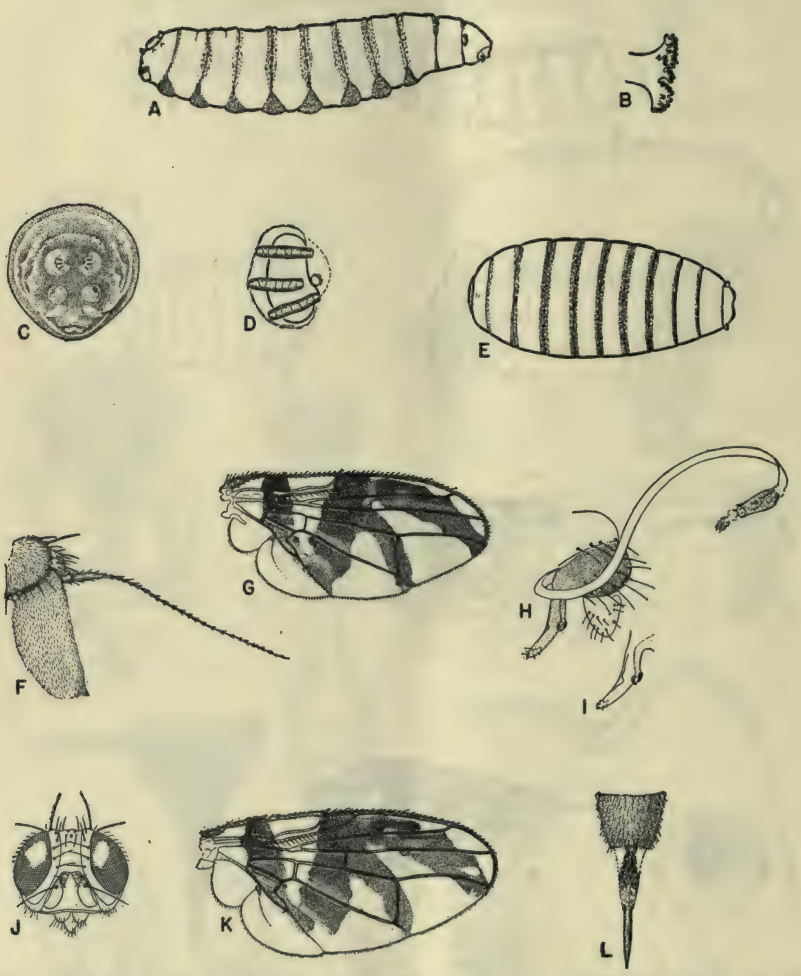


FIGURE 13.—*Rhagoletis pomonella:* *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (side view); *I*, inner surface of right half of forceps of male genitalia (side view); *J*, head of adult female (front view); *K*, wing of adult female: *L* ovipositor sheath and fully extruded ovipositor (upper aspect).

FIGURE 14.—*Rhagoletis zephyria* (from atypical Florida specimens): *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (side view); *I*, inner surface of right half of forceps of male genitalia (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

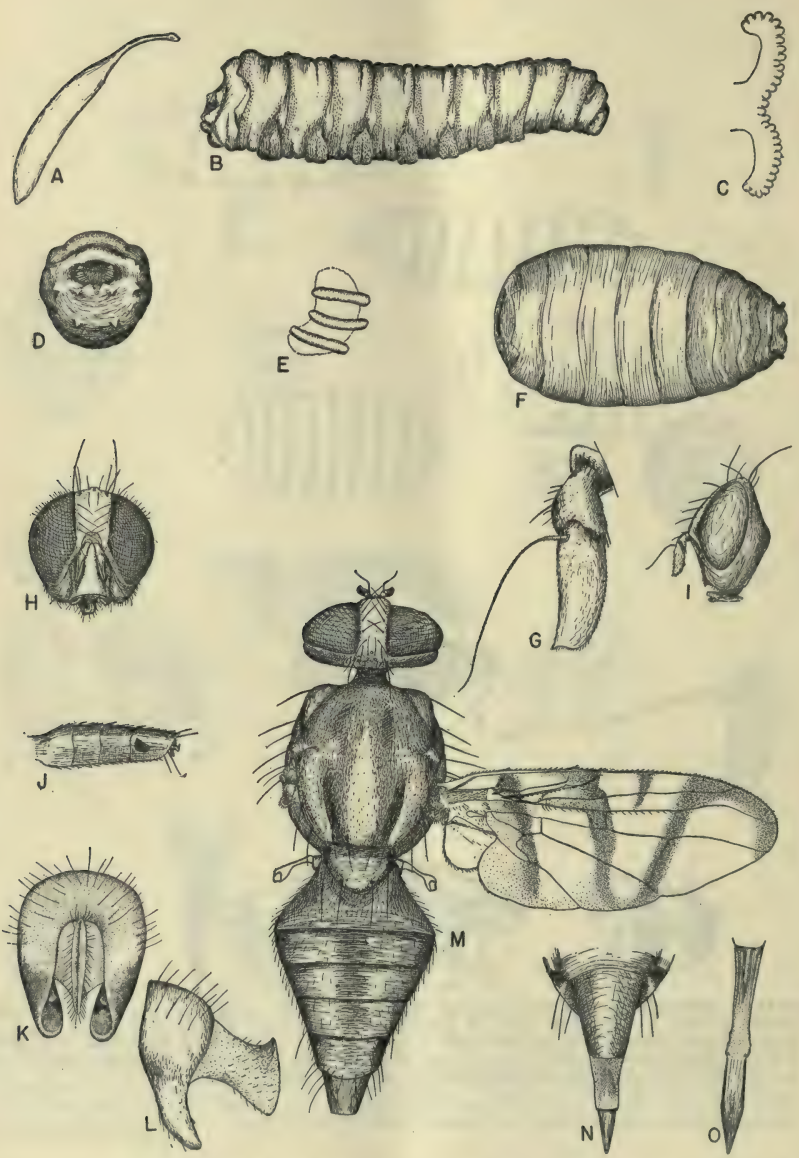


FIGURE 15.—*Zonosemata electa: A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, head of adult male (front view); *I*, same (side view); *J*, abdomen of adult male (side view); *K*, male genitalia (from anal end); *L*, same (side view); *M*, adult female; *N*, ovipositor sheath showing ovipositor partly extruded (from below); *O*, ovipositor (from below).

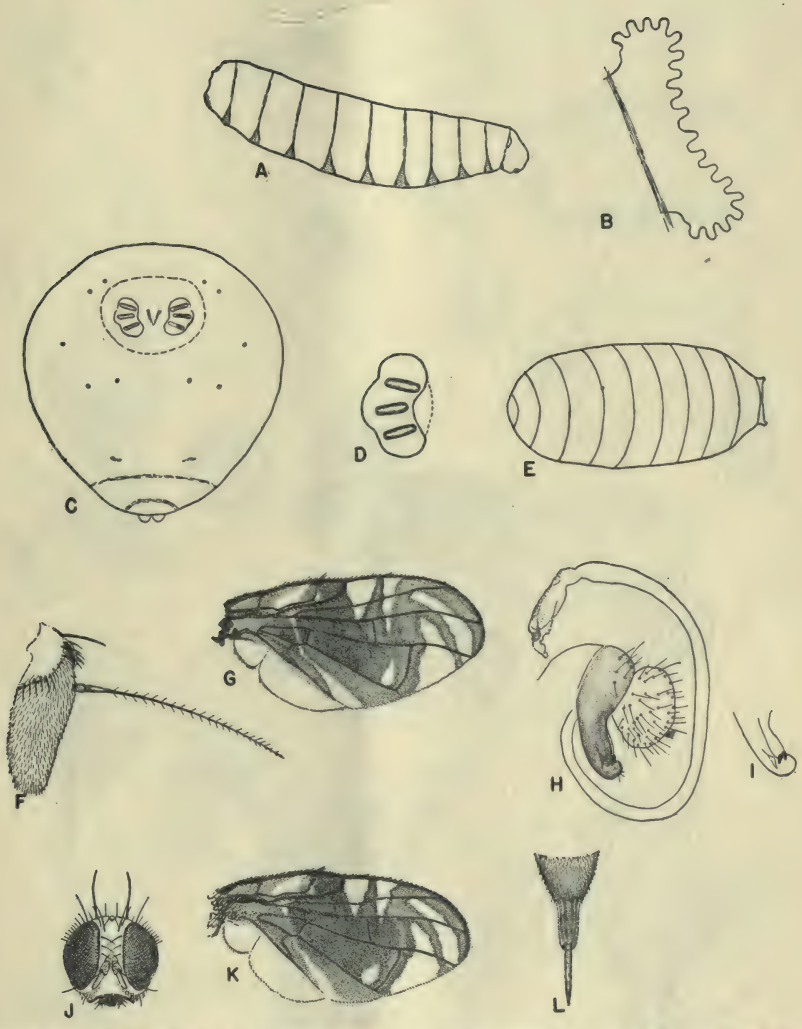


FIGURE 16.—*Myoleja limata:* *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (side view); *I*, inner surface of right half of forceps of male genitalia (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

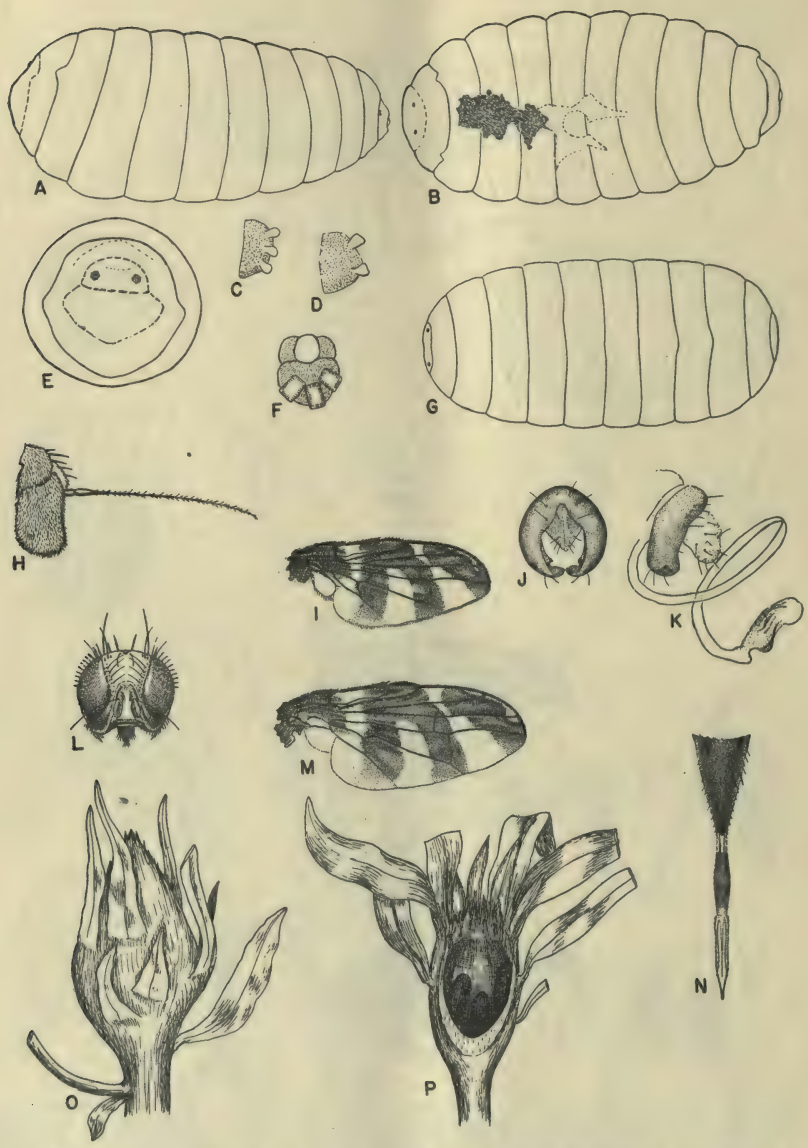


FIGURE 17.—*Procecidochares australis: A*, Larva (side view); *B*, larva (upper aspect); *C*, anterior spiracle of larva showing three beads; *D*, same but showing only two beads; *E*, larva (rear view); *F*, posterior spiracle of larva; *G*, puparium (upper aspect); *H*, antenna of male; *I*, wing of adult male; *J*, male genitalia (from anal end); *K*, same (side view); *L*, head of adult female; *M*, wing of adult female; *N*, ovipositor sheath and fully extruded ovipositor; *O*, gall on *Heterotheca subaxillaris; P*, same cut open and showing puparia.

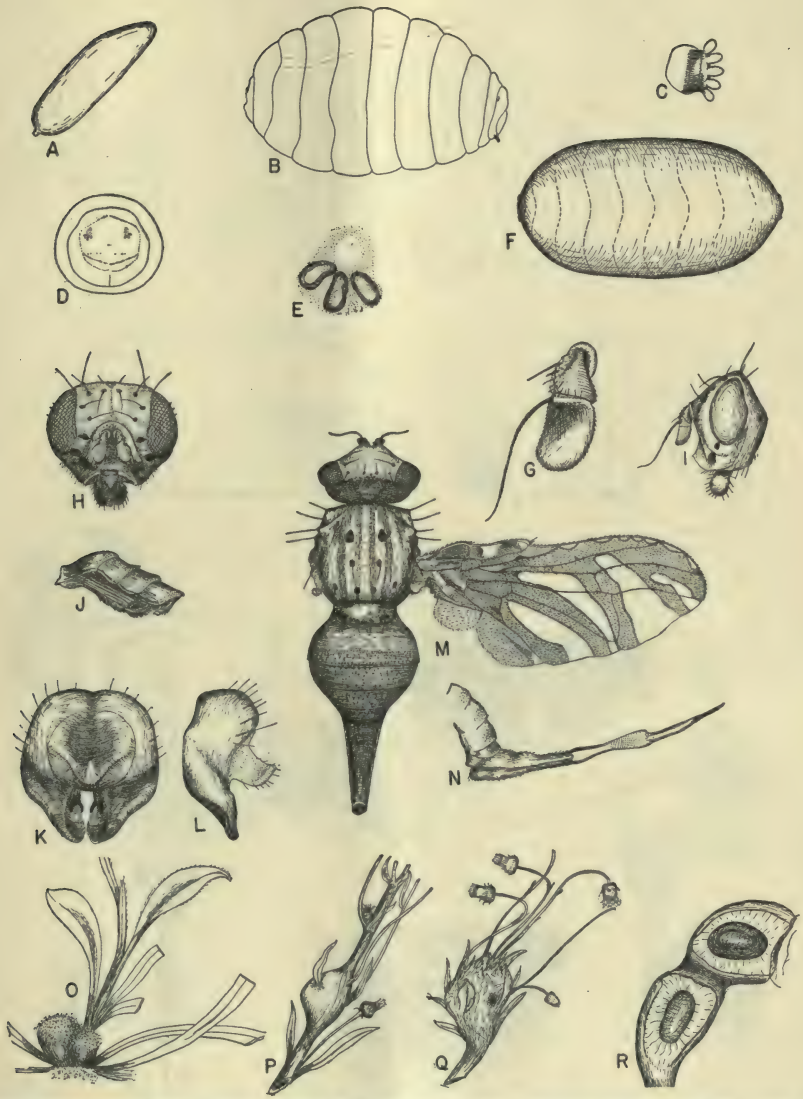


FIGURE 18.—*Peronyma maculata:* *A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, two posterior segments of larva (rear view); *E*, posterior spiracle; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, head of adult male (front view); *I*, same (side view); *J*, abdomen of adult male (side view); *K*, male genitalia (from anal end); *L*, same (side view); *M*, adult female; *N*, part of abdomen of adult female showing ovipositor sheath and completely extruded ovipositor (side view); *O*, two galls on the root crown of *Chrysopsis trichophylla;* *P*, gall on the stem of *C. trichophylla;* *Q*, gall at the bases of flowers and showing exit hole; *R*, two galls cut open, the upper one showing a puparium.

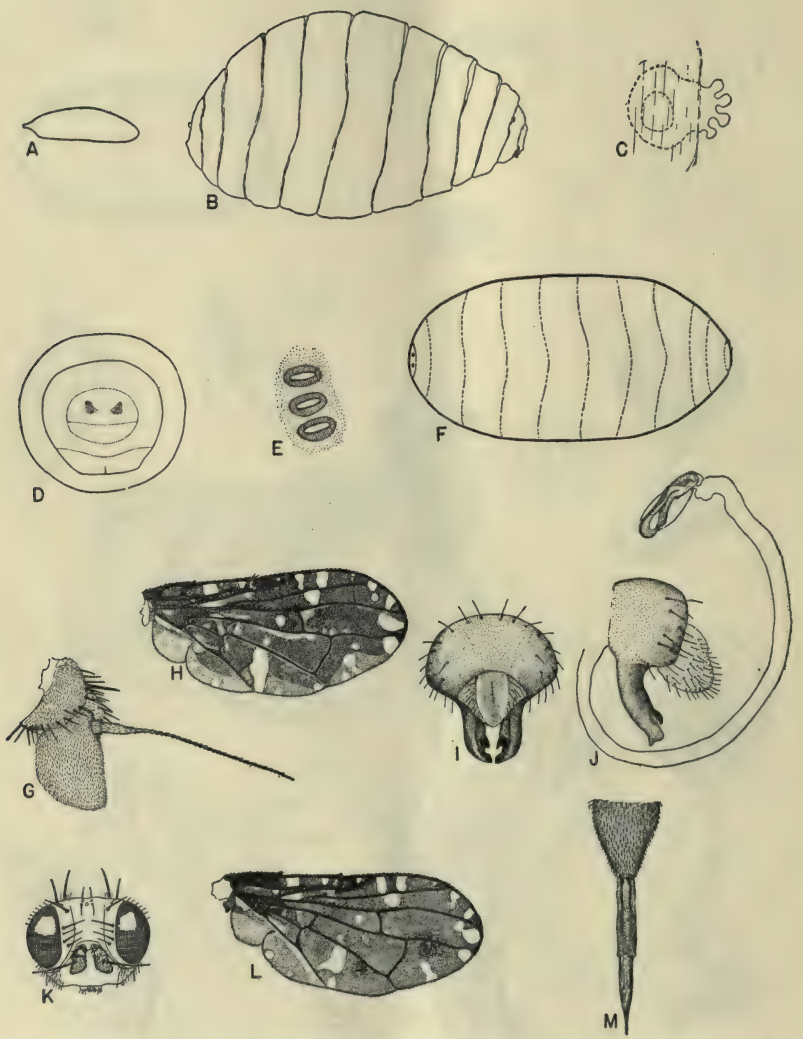


FIGURE 19.—*Eurosta nicholsoni*, new species: *A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, two posterior segments of larva (rear view); *E*, posterior spiracle; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, wing of adult male; *I*, male genitalia (from anal end); *J*, same (side view); *K*, head of adult female; *L*, wing of adult female; *M*, ovipositor sheath and completely extruded ovipositor (upper aspect).

FIGURE 20.—*Eurosta comma: A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, two posterior segments of larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, wing of adult male; *I*, male genitalia from anal end); *J*, same (side view); *K*, head of adult female; *L*, wing of adult female; *M*, ovipositor sheath and completely extruded ovipositor (upper aspect).

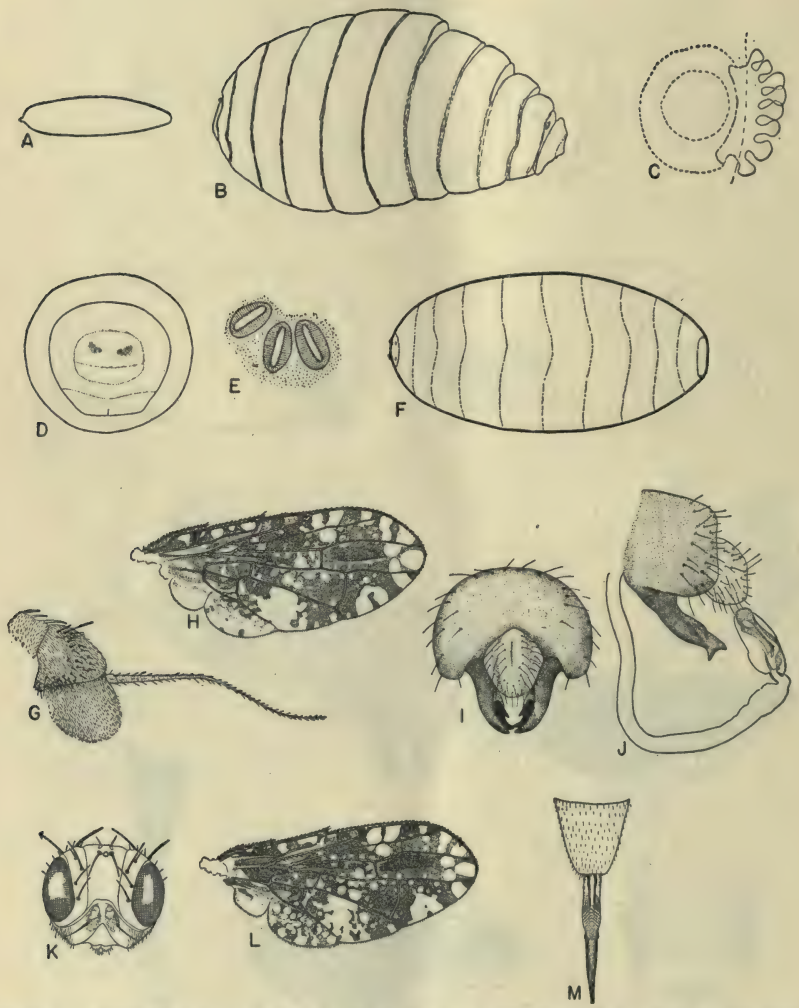


FIGURE 21.—*Eurosta reticulata: A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, two posterior segments of larva (rear view); *E*, posterior spiracle; *F*, puparium (upper aspect); *G*, antenna of adult male (from inner side); *H*, wing of adult male; *I*, male genitalia (from anal end); *J*, same (side view); *K*, head of adult female; *L*, wing of adult female; *M*, ovipositor sheath and completely extruded ovipositor (upper aspect).

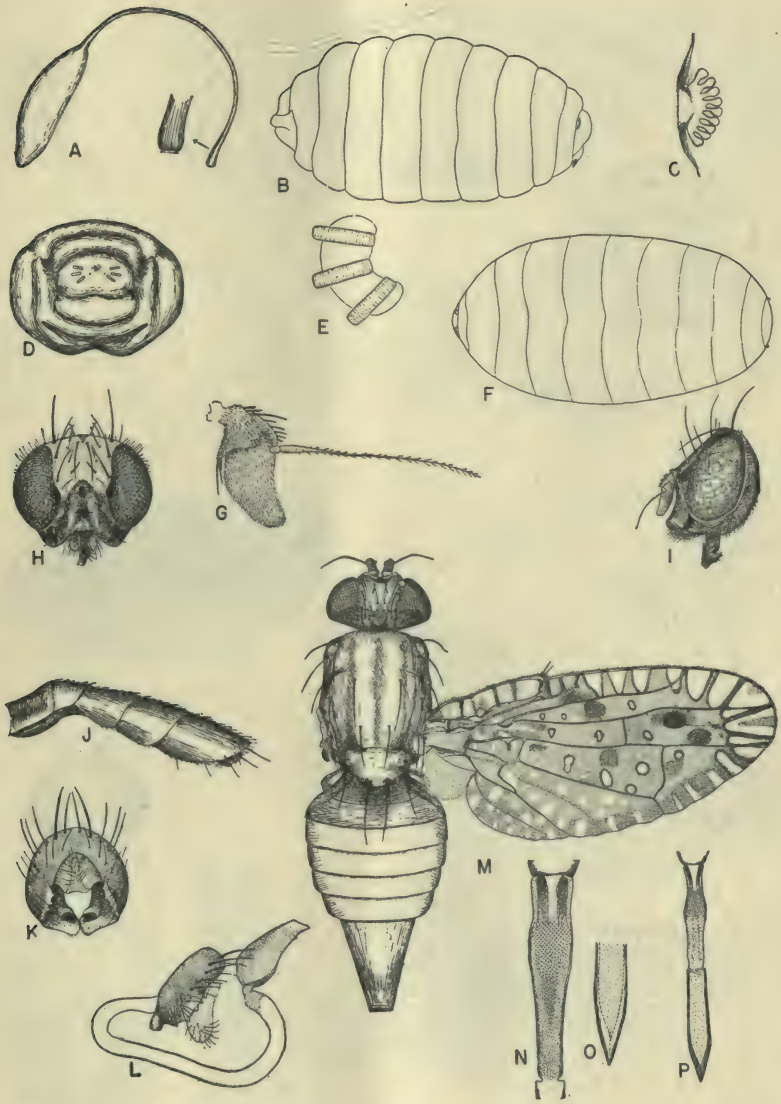


FIGURE 22.—*Paracantha culta:* *A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, two posterior segments of larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, head of adult male (front view); *I*, same (side view); *J*, abdomen of adult male (side view); *K*, male genitalia (from anal end); *L*, same (side view); *M*, adult female; *N*, membrane connecting ovipositor and ovipositor sheath showing armature; *O*, tip of ovipositor; *P*, tip of ovipositor sheath and fully extruded ovipositor (upper aspect).

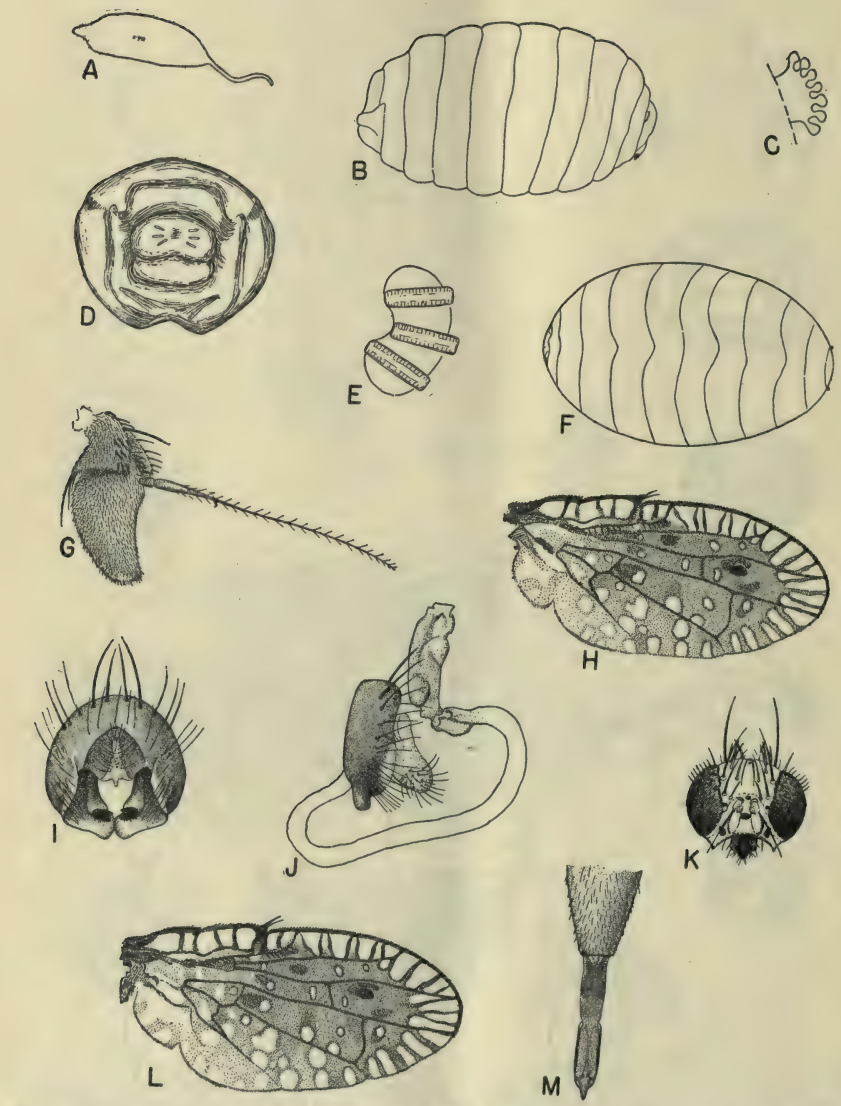


FIGURE 23.—*Paracantha forficula*, new species: *A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, two posterior segments of larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, wing of adult male; *I*, male genitalia (from anal end); *J*, same (side view); *K*, head of adult female (front view); *L*, wing of adult female; *M*, ovipositor fully extruded from the ovipositor sheath (upper aspect).

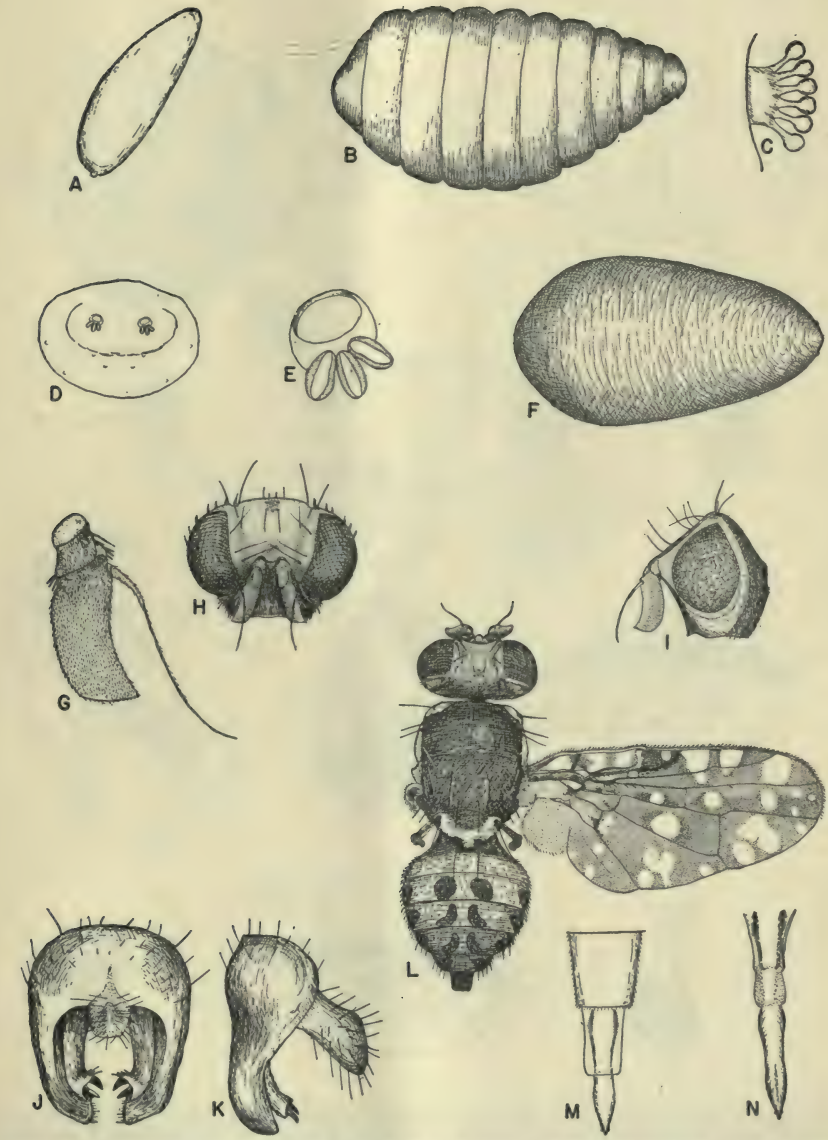


FIGURE 24.—*Acidogona melanura: A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, upper half of posterior segment of larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, head of adult male (front view); *I*, same (side view); *J*, male genitalia (from anal end); *K*, same (side view); *L*, adult female; *M*, ovipositor sheath and partly extruded ovipositor (upper aspect); *N*, ovipositor (from below).

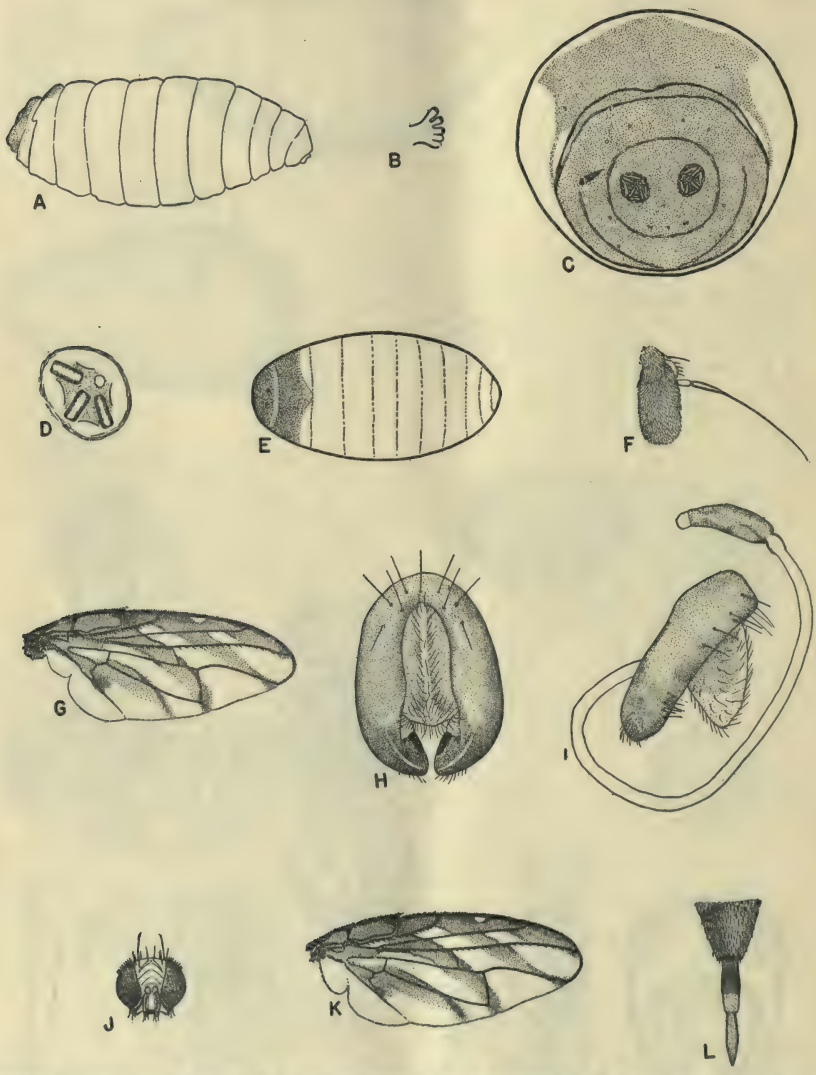


FIGURE 25.—*Tomoplagia obliqua: A*, Larva (side view); B, anterior spiracle of larva; *C*, two posterior segments of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female; *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

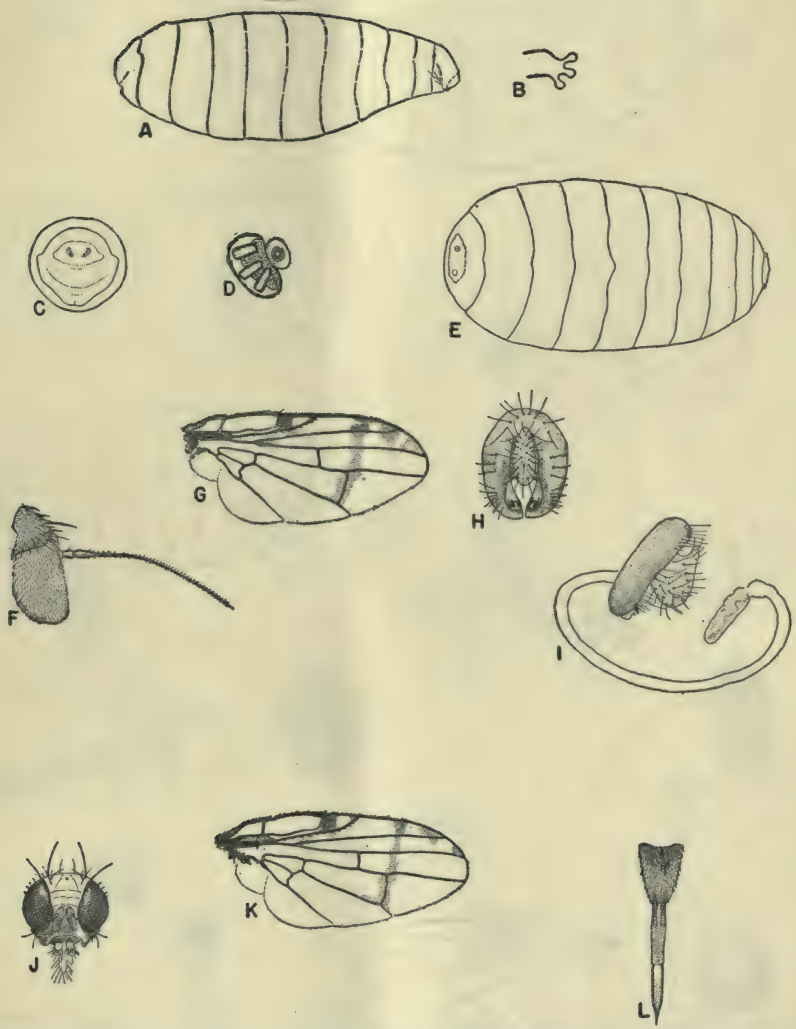


FIGURE 26.—*Neaspilota achilleae:* *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, two posterior segments of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

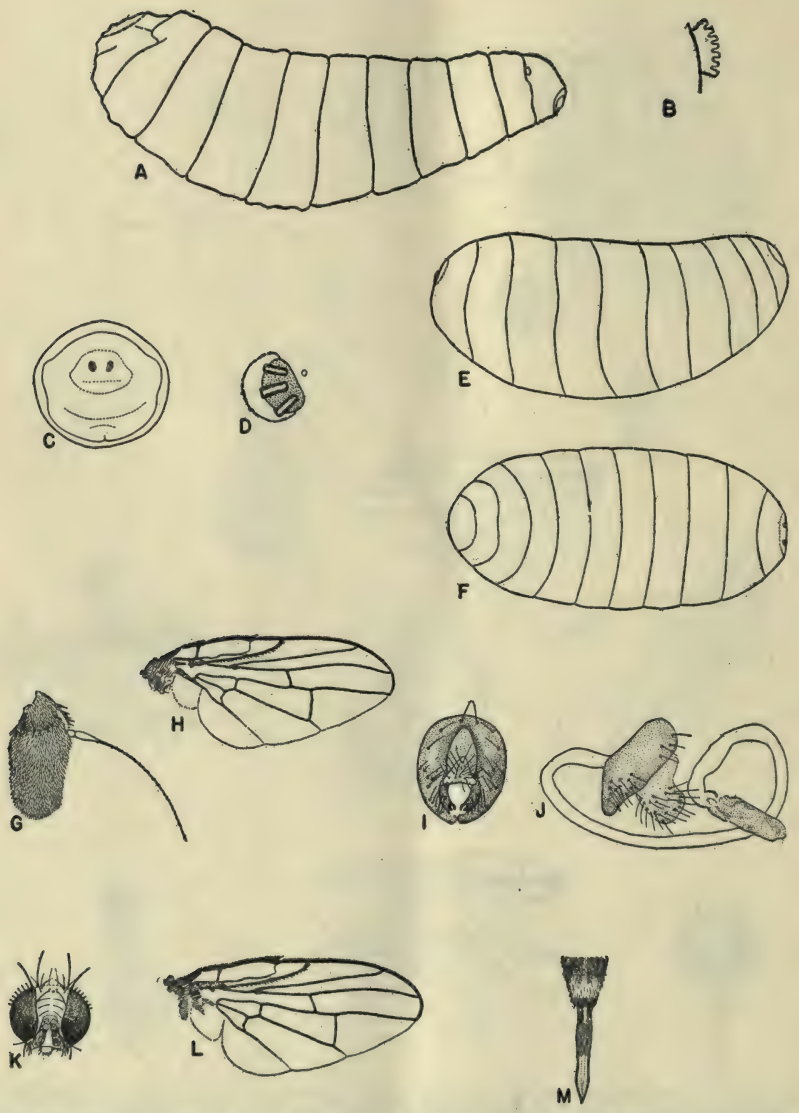


FIGURE 27.—*Neaspilota alba:* *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, two posterior segments of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (side view); *F*, same (upper aspect); *G*, antenna of adult male; *H*, wing of adult male; *I*, male genitalia (from anal end); *J*, same (side view); *K*, head of adult female (front view); *L*, wing of adult female; *M*, ovipositor sheath and fully extruded ovipositor (upper aspect).

FIGURE 28.—*Neaspilota punctistigma*, new species: *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, two posterior segments of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

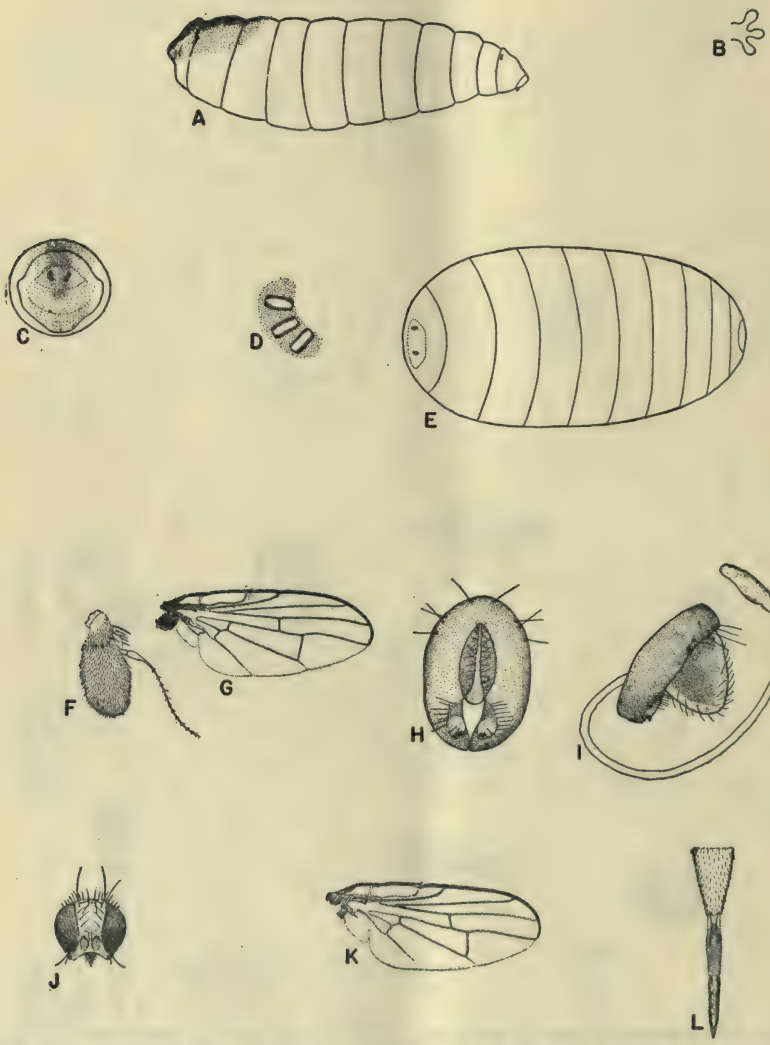


FIGURE 29.—*Neaspilota dolosa*, new species: *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, two posterior segments of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

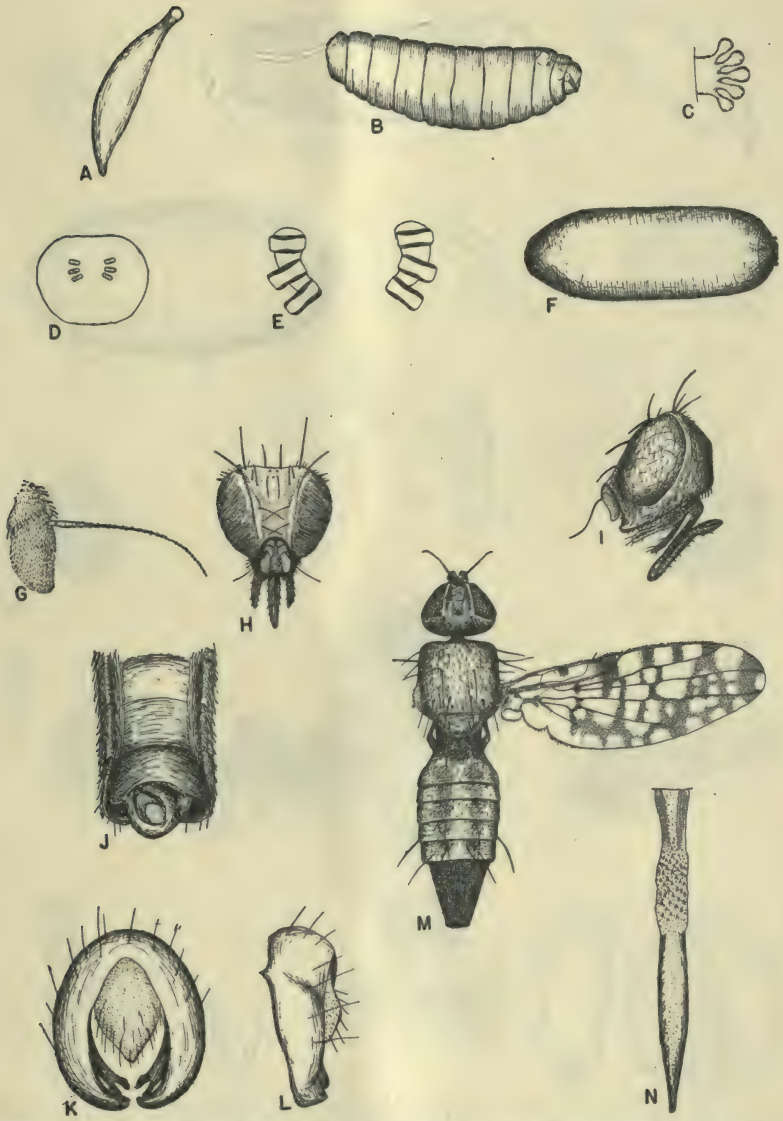


FIGURE 30.—*Paroxyna picciola: A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, upper half of posterior segment of larva (rear view); *E*, posterior spiracles of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, head of adult female (front view); *I*, same (side view); *J*, terminal segments of abdomen of adult male with genitalia in natural position (from below); *K*, male genitalia (from anal end); *L*, same (side view); *M*, adult female; *N*, ovipositor with membrane showing armature (upper aspect).

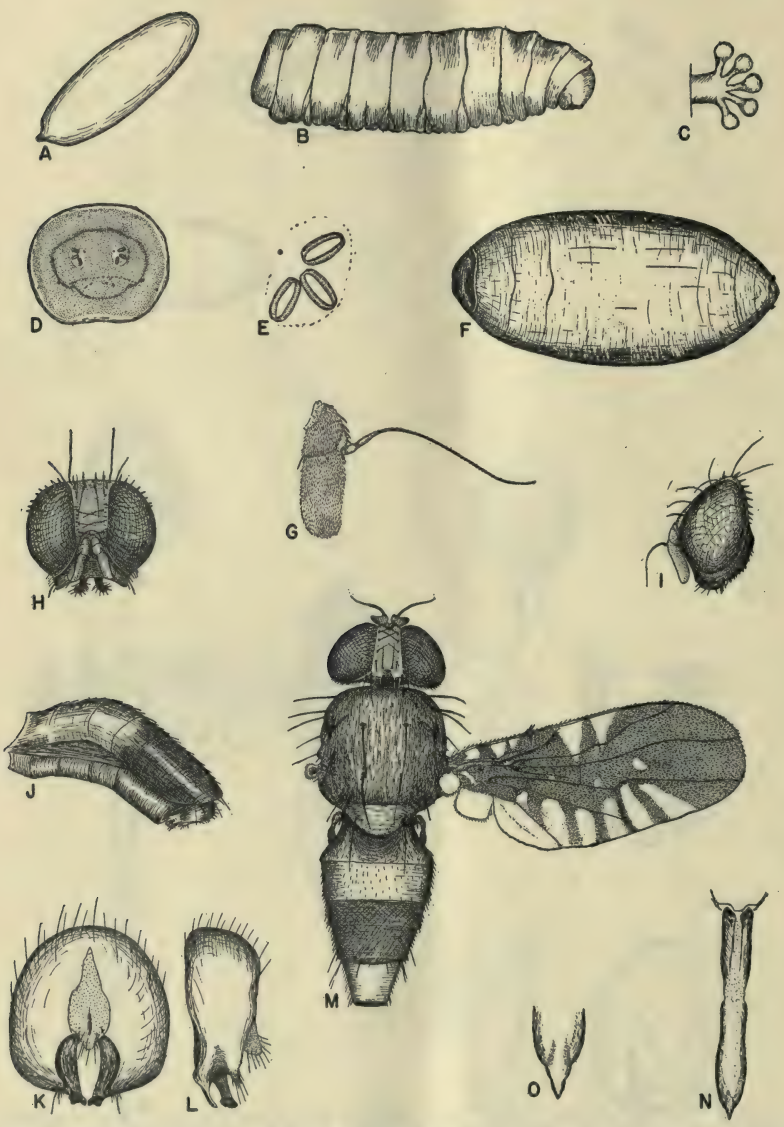


FIGURE 31.—*Xanthaciura insecta: A*, Egg; *B*, larva (side view); *C*, anterior spiracle of larva; *D*, posterior segment of larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, head of adult female (front view); *I*, same (side view); *J*, abdomen of adult male with genitalia in natural position (side view); *K*, male genitalia (from anal end); *L*, same (side view); *M*, adult female; *N*, ovipositor with membrane (upper aspect); *O*, tip of ovipositor (upper aspect).

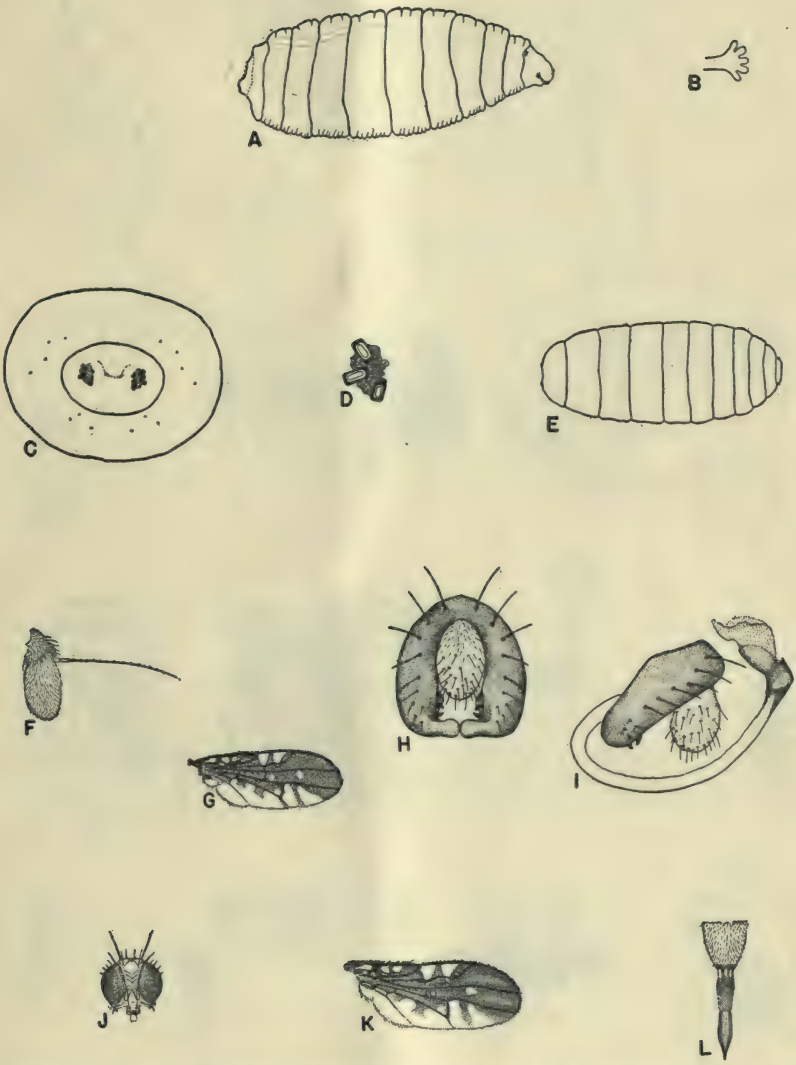


FIGURE 32.—*Xanthaciura connexionis*, new species: *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, posterior segment of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath with fully extruded ovipositor (upper aspect).

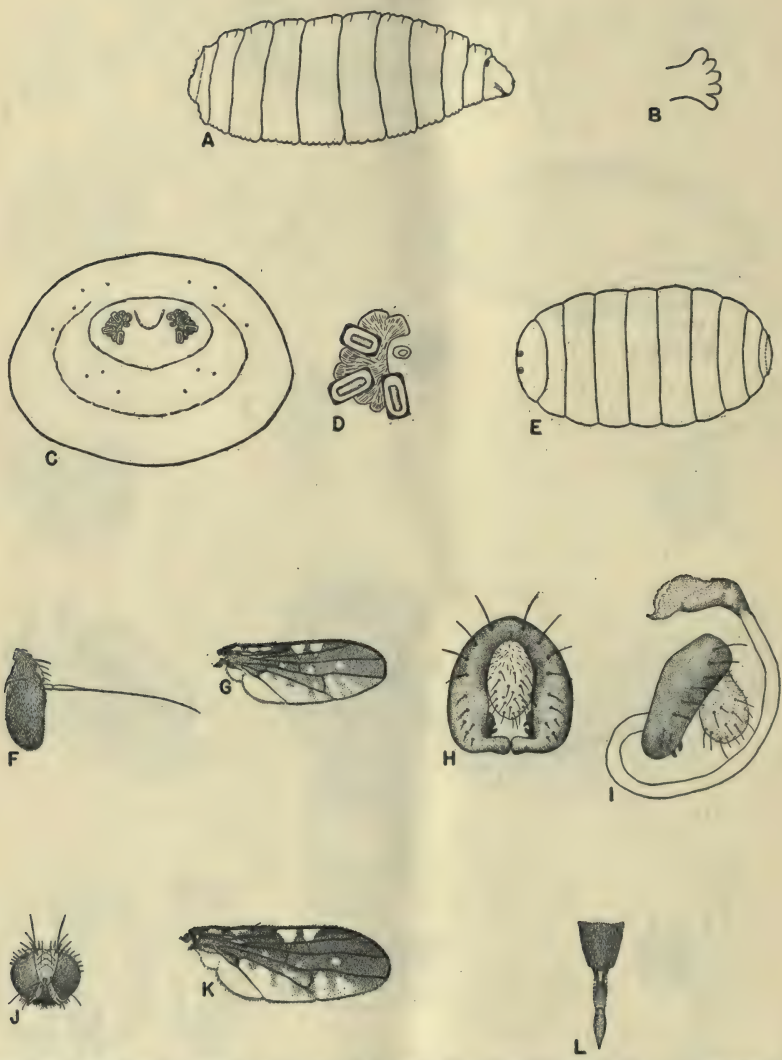


FIGURE 33.—*Xanthaciura tetraspina: A*, Larva (side view); *B*, anterior spiracle of larva; *C*, posterior segment of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath with fully extruded ovipositor (upper aspect).

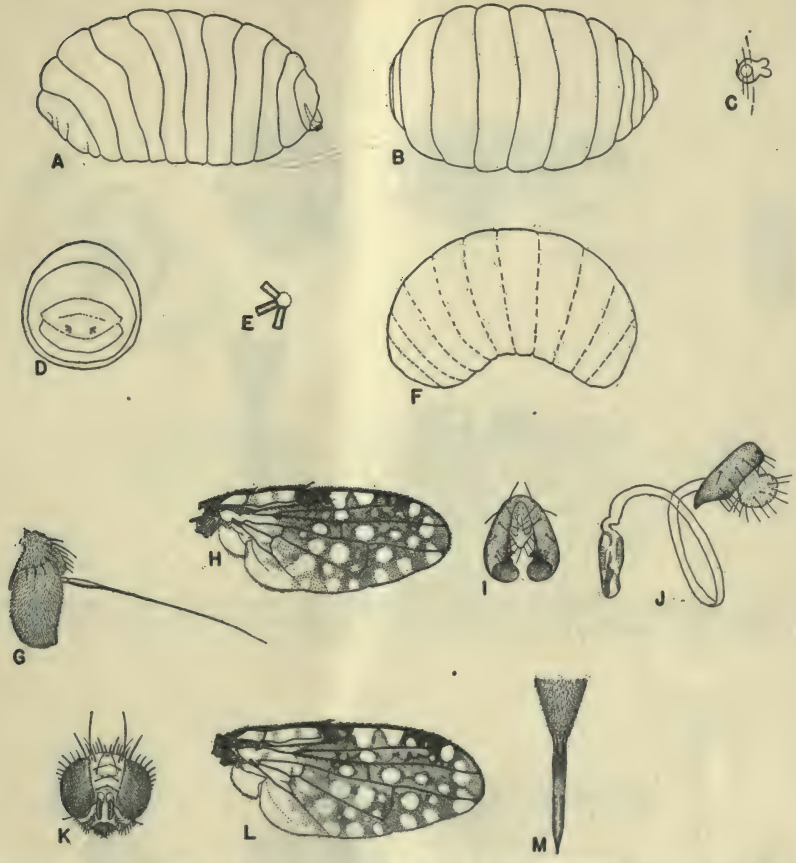


FIGURE 34.—*Acinia fucata: A*, Larva (side view); *B*, larva from above; *C*, anterior spiracle of larva; *D*, two posterior segments of larva (rear view); *E*, posterior spiracle of larva; *F*, puparium (side view); *G*, antenna of adult male; *H*, wing of adult male; *I*, male genitalia (from anal end); *J*, same (side view); *K*, head of adult female (front view); *L*, wing of adult female; *M*, ovipositor sheath and fully extruded ovipositor (upper aspect).

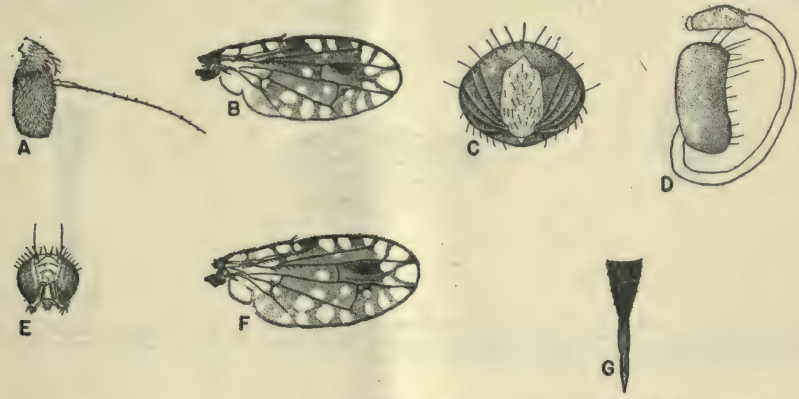


FIGURE 35.—*Euaresta bella: A*, Antenna of adult male; *B*, wing of adult male; *C*, male genitalia (from anal end); *D*, same (side view); *E*, head of adult female (front view); *F*, wing of adult female; *G*, ovipositor sheath and fully extruded ovipositor (upper aspect).

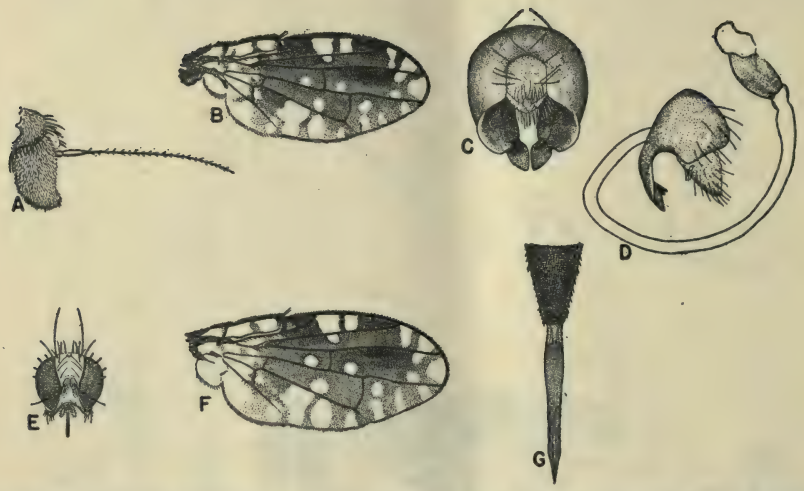


FIGURE 36.—*Dyseuaresta mexicana: A,* Antenna of adult male; *B,* wing of adult male; *C,* male genitalia (from anal end); *D,* same (side view); *E,* head of adult female (front view); *F,* wing of adult female; *G,* ovipositor sheath and fully extruded ovipositor (upper aspect).

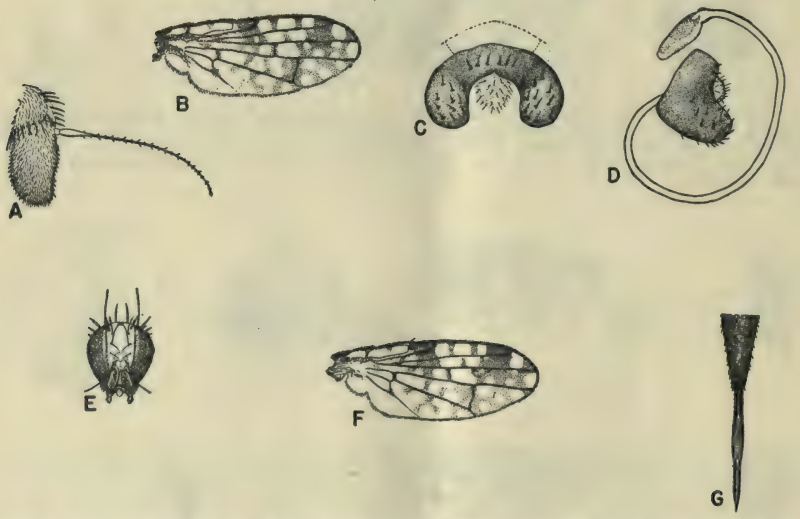


FIGURE 37.—*Parozyna thomae: A,* Antenna of adult male; *B,* wing of adult male; *C,* male genitalia (from anal end); *D,* same (side view); *E,* head of adult female (front view); *F,* wing of adult female; *G,* ovipositor sheath and fully extruded ovipositor (upper aspect).

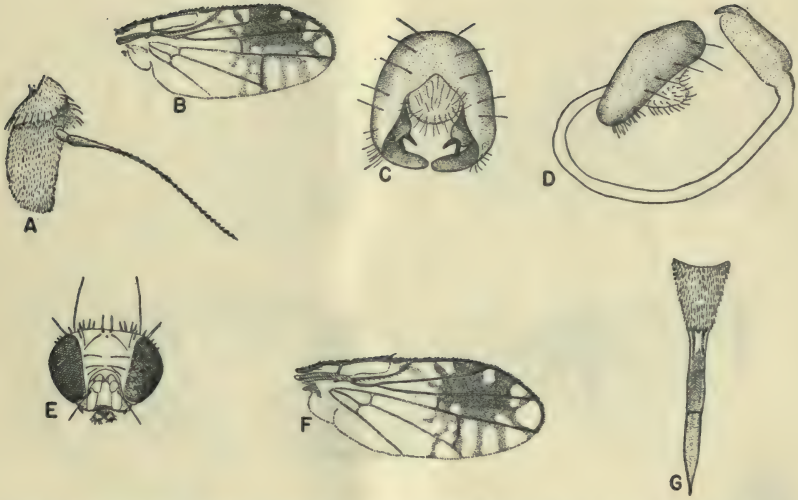


FIGURE 38.—*Trupanea* (*Trupanea*) *dacetoptera: A*, Antenna of adult male; *B*, wing of adult male; *C*, male genitalia (from anal end); *D*, same (side view); *E*, head of adult female (front view); *F*, wing of adult female; *G*, ovipositor sheath and fully extruded ovipositor (upper aspect).

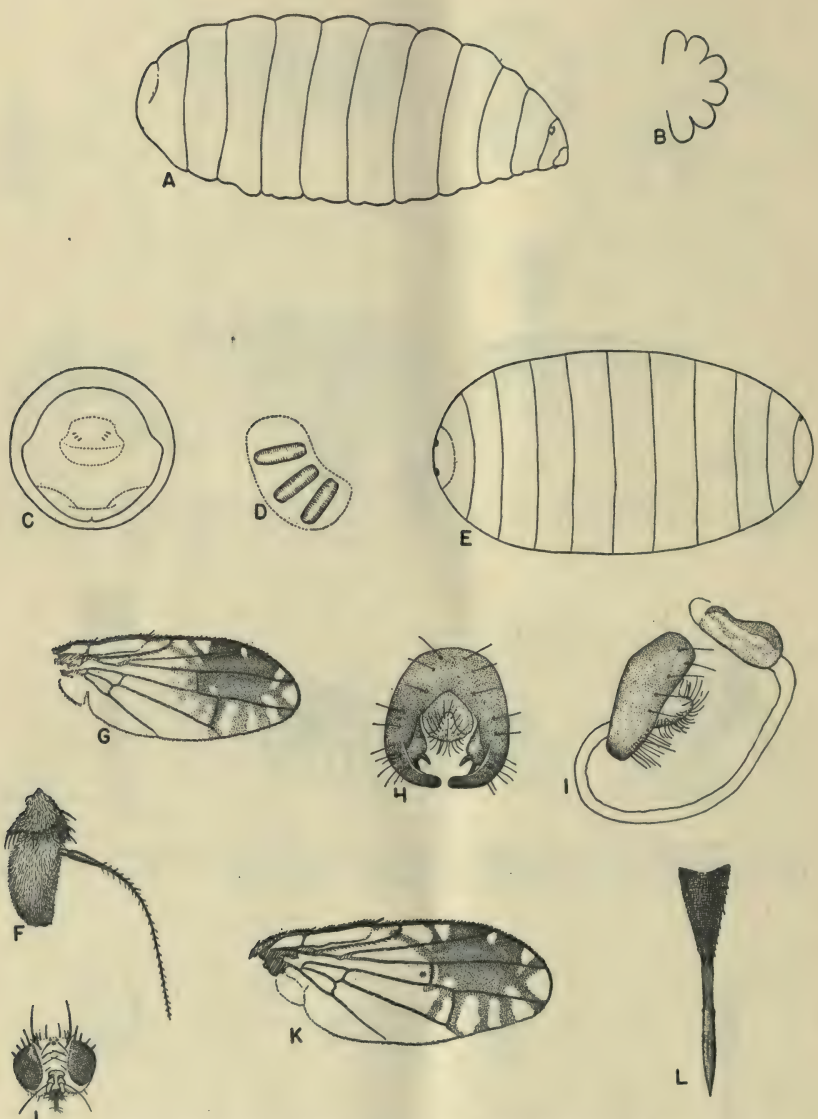


FIGURE 39.—*Trupanea* (*Trupanea*) *mevarna: A*, Larva (side view); *B*, anterior spiracle of larva; *C*, two posterior segments of larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

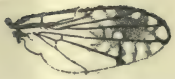

FIGURE 40.—*Trupanea* (*Trupanea*) *ageratae*, new species: Wing of adult male.

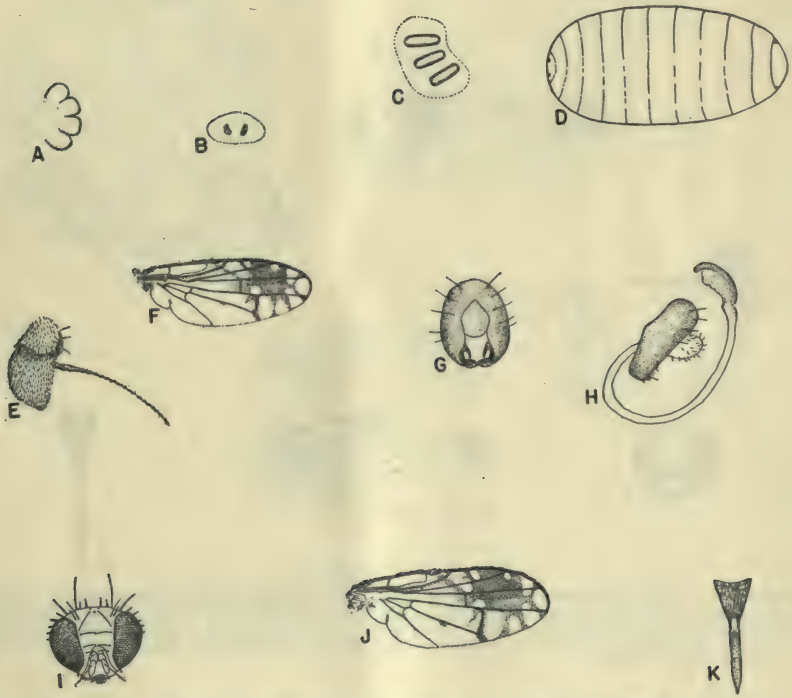


FIGURE 41.—*Trupanea* (*Trupanea*) *actinobola: A*, Anterior spiracle of puparium; *B*, posterior spiracular area of puparium (rear view); *C*, posterior spiracle of puparium; *D*, puparium (upper aspect); *E*, antenna of adult male; *F*, wing of adult male; *G*, male genitalia (from anal end); *H*, same (side view); *I*, head of adult female (front view); *J*, wing of adult female; *K*, ovipositor sheath and fully extruded ovipositor (upper aspect).

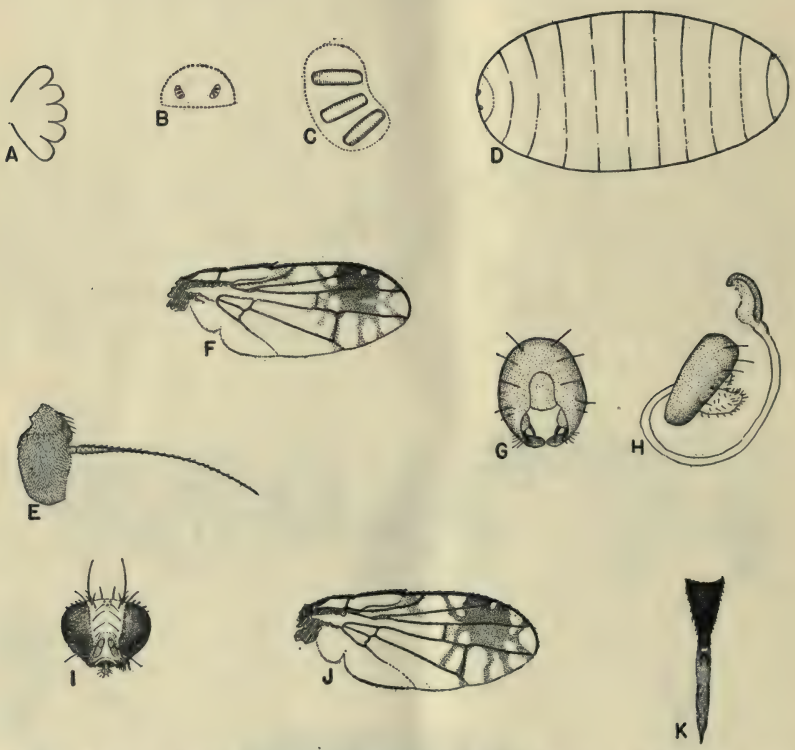


FIGURE 42.—*Trupanea* (*Trupanea*) *eclipta*, new species: *A*, Anterior spiracle of puparium; *B*, posterior spiracular area of puparium (rear view); *C*, posterior spiracle of puparium; *D*, puparium (upper aspect); *E*, antenna of adult male; *F*, wing of adult male; *G*, male genitalia (from anal end); *H*, same (side view); *I*, head of adult female (front view); *J*, wing of adult female; *K*, ovipositor sheath and fully extruded ovipositor (upper aspect).

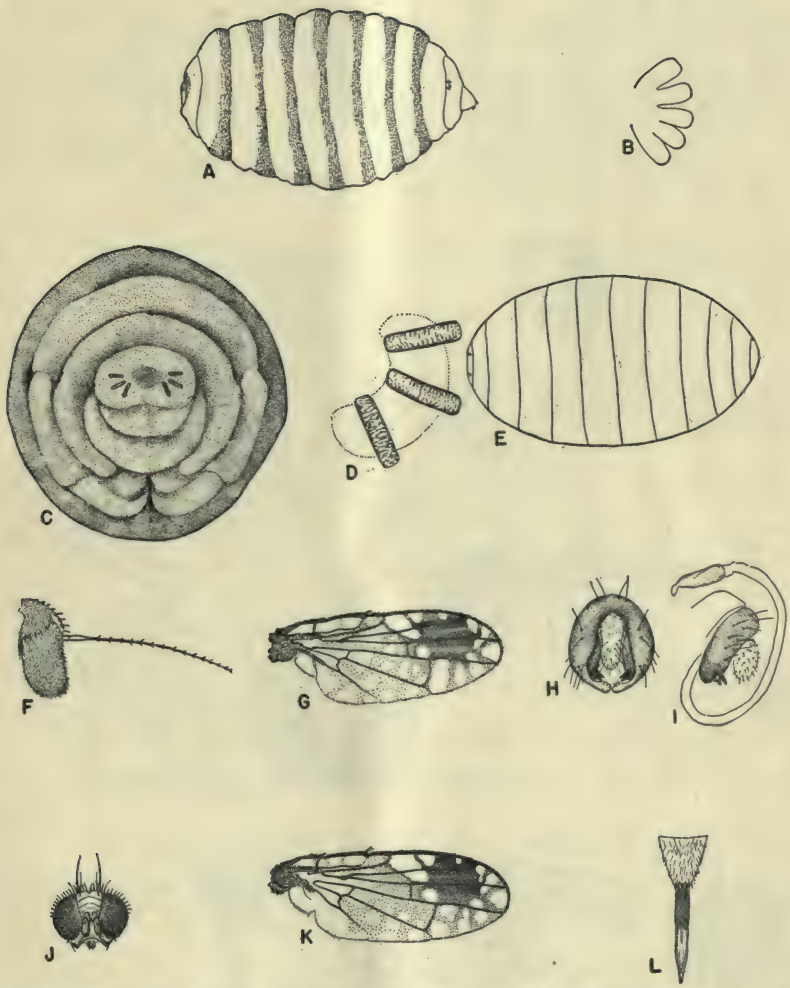


FIGURE 43.—*Trupanea* (*Euarestoides*) *abstersa: A*, Larva (side view); *B*, anterior spiracle of larva; *C*, larva (rear view); *D*, posterior spiracle of larva; *E*, puparium (upper aspect); *F*, antenna of adult male; *G*, wing of adult male; *H*, male genitalia (from anal end); *I*, same (side view); *J*, head of adult female (front view); *K*, wing of adult female; *L*, ovipositor sheath and fully extruded ovipositor (upper aspect).

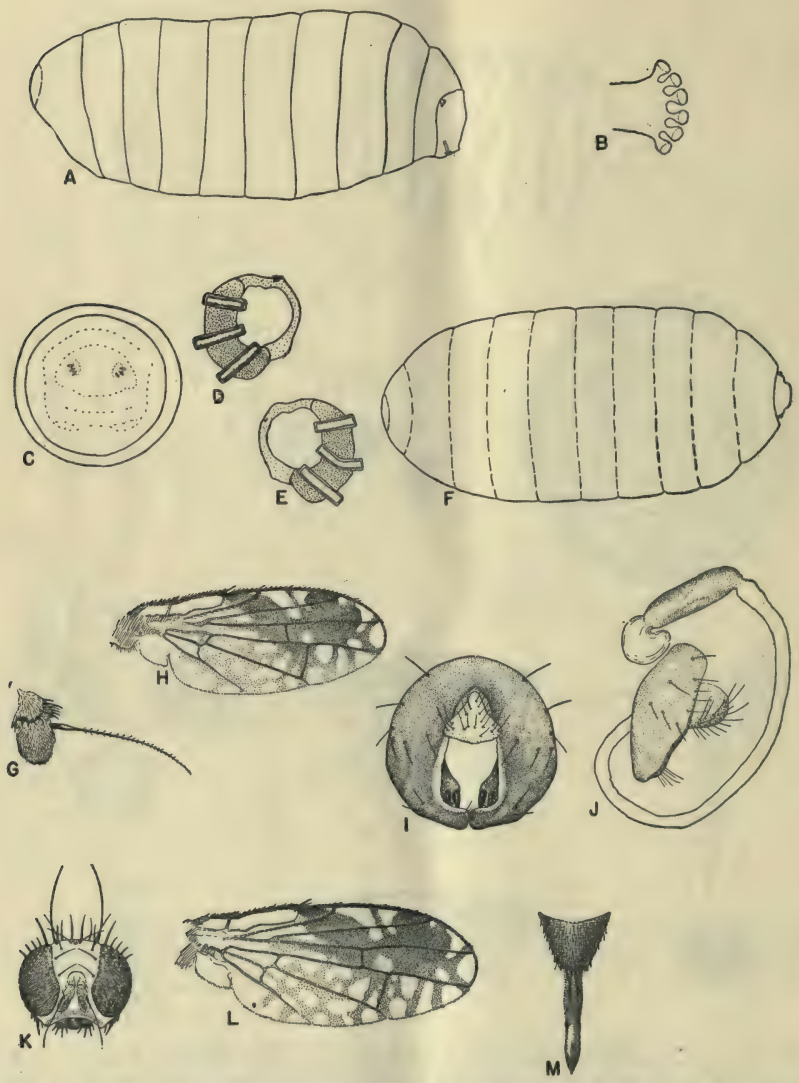


FIGURE 44.—*Trupanea* (*Tephritoides*) *subpura*: *A*, Larva (side view); *B*, anterior spiracle of larva; *C*, two posterior segments of larva (rear view); *D*, posterior spiracle of larva showing straight slits; *E*, same but showing one of the slits bent; *F*, puparium (upper aspect); *G*, antenna of adult male; *H*, wing of adult male; *I*, male genitalia (from anal end); *J*, same (side view); *K*, head of adult female (front view); *L*, wing of adult female; *M*, ovipositor sheath and fully extruded ovipositor (upper aspect).

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